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ON THE PRE-CAMBRIAN ROCKS OF THE BRITISH ISLES.

DURING the last twenty years much has been written about the "pre-Cambrian" rocks of the British Isles. Unfortunately when attention began to be sedulously given to the study of these ancient formations, the problems of metamorphism were still a hundred fold more obscure than they have since become; the aid of the microscope had not been seriously and systematically adopted for the investigation of the crystalline schists, and geologists generally were still under the belief that the broad structure of these schists could be treated like those of the sedimentary rocks, and be determined by rapid traverses of the ground. We have now painfully discovered that these older methods of observation were extremely crude, and that the work performed in accordance with them is now of little interest or value save as a historical warning to future generations of geologists. Geological literature has meanwhile been burdened with numerous contributions which remain as a permanent incubus on our library shelves.

It may serve a useful purpose at the present time in possibly aiding those who are engaged in the study of the oldest rocks of North America, if I place before them, as briefly as possible, the main facts which in my opinion have now been satisfactorily proved regarding the corresponding rocks of Britain, and if I indicate at the same time some of the more probable inferences in those cases where the facts, at present known, do not warrant a definite conclusion.

It is obvious that in any effort to establish that a group of rocks is older than the very base of the sedimentary fossiliferous formations, we must somewhere find that group emerging from under the bottom of these formations. Until lithological characters are ascertained to be so distinctive and constant as to be comparable to fossil evidence for purposes of stratigraphical identification, we should not assume that detached areas of older rocks rising amid Palæozoic, Secondary or Tertiary formations are pre-Cambrian. We should, if possible, begin at the bottom of the Palæozoic systems and work backward, tracing each successive system or group as these rise from under each other, until we arrive at what appears to be the oldest traceable within the region of observation. It is clear that in the present state of knowledge we have no satisfactory means of identifying such successive systems in widely separated countries. All that can be attempted in the meantime is to ascertain the special types in each region, and to point out their general resemblances or contrasts to those of other regions. It is better to avoid confusion by refraining from applying the stratigraphical names adopted for the oldest rocks of one region to those of another geographically remote, though we may hope that eventually it may be possible to work out the equivalence of these local names.

In the British Isles, by much the most important region for the study of the oldest rocks is to be found in the north-west Highlands of Scotland. The very basement strata of the Cambrian system are there traceable for a distance of more than 100 miles, reposing with a strong unconformability upon all rocks of older date. They consist of dolomitic shales with *Olenellus*, resting upon a thick group of quartzites, full of annelid tubes. One of the most remarkable features of these ancient strata is the persistence of their component bands or zones which, though sometimes only a few feet thick, can be traced throughout the whole tract of country just referred to. For the study of the pre-Cambrian rocks this is an important point, for we can be quite certain that even where fossil evidence locally fails, the

same basement members of the Cambrian system are persistent and lie directly upon the pre-Cambrian series.

Lewisian Gneiss. Ever since the researches of Murchison and Nicol in the north-west of Scotland, it has been known that two distinct systems of rock underlie the quartzites to which I have just alluded. Murchison regarded the upper of these as of Cambrian age, while he assigned the unconformable quartzites and limestones above it to the Lower Silurian period. But the recent discovery of the *Olenellus* zone intercalated conformably between the quartzites and the overlying limestones may be regarded as proving that all the rocks which underlie the quartzites and are separated from them by a strong unconformability must be pre-Cambrian. It is thus established beyond any reasonable doubt that two great pre-Cambrian systems of rock exist in the north-west of Scotland.

These two systems differ so entirely from each other that their respective areas can be defined with minute accuracy. The uppermost consists chiefly of dull reddish sandstones with conglomerates, and especially towards their base in Rosshire, some bands of dark grey shale, the whole having a thickness of at least 8,000 or 10,000 feet, though as both the base and the top of the series are marked by strong unconformabilities, the whole original thickness of deposits is nowhere seen. As these rocks are well developed around Loch Torridon, they were named by Nicol the Torridon Sandstone—a designation which has more recently been shortened into "Torridonian." The lower system is mainly composed of various foliated rocks which may be embraced under the general term "gneiss." These masses present the usual characters of the so-called "fundamental complex" "Urgebirge," or "Archæan Series" of other countries. The contrast between the thoroughly crystalline, gnarled, ancient-looking gneisses below, and the overlying, nearly horizontal Torridonian conglomerates, sandstones, and shales, which are largely made out of their debris, is so striking that every observer feels persuaded that in any logical system of classification they can not be both placed in the same division of the geolog-

ical record. They are certainly both pre-Cambrian, but they must belong to widely separated eras, and must have been produced by entirely different processes. If it is proposed to regard the gneisses as "Archæan," we must refuse to include the Torridonian strata in the same section of pre-Cambrian time. But so much uncertainty exists as to the application of this term Archæan, examples are so multiplying wherein what was supposed to be the oldest and truly Archæan rock is found to be intrusive in rocks that were taken to be of much younger date, and there are such slender grounds for correlating the so-called Archæan rocks of one country with those of another, that I prefer for the present, at least, not to use the term at all. Let me very briefly state some of the main characteristics of the two sharply contrasted rock-systems of the north-west of Scotland.

The oldest gneiss of that region was originally called "Lewisian" by Murchison, from its large development in the Island of Lewis, and I think it would be, for the present at least, an advantage to retain this geographical appellation. At first this "fundamental gneiss" was thought to be a comparatively simple formation, and the general impression probably was that it should be regarded as a metamorphic mass, produced mainly from the alterations of very ancient stratified rocks. Its foliation-planes were believed to be those of original deposit which by terrestrial disturbance had been thrown into numerous plications and corrugated puckerings. But a detailed study of this primeval rock has revealed in it a far more complicated structure. The supposed bedding-planes have been ascertained to have nothing to do with sedimentary stratification, and the gneiss has been resolved into a complex series of eruptive rocks, varying from a highly basic to an acid type, and manifestly belonging to different times of extrusion. With the exception of one district, to which I shall immediately refer, no part of the whole region yet examined has revealed to the rigid scrutiny of my colleagues of the Geological Survey, any trace of rocks which can be regarded as probably of other than igneous origin. It is true that our researches have been hitherto confined to the mainland

of Scotland, the large area of the Outer Hebrides, which consists of similar gneisses, remaining to be explored. It is therefore possible that indisputable evidence of an ancient sedimentary series through which the gneiss was originally protruded, may yet be discovered in the unexplored islands. But taking the gneiss as at present known in Sutherland and Rosshire, we find it to be generally coarse in texture, rudely foliated, and passing sometimes into massive types in which foliation is either faintly developed or entirely absent. Much of this gneiss is considerably more basic than the more typical rocks to which the term gneiss was formerly restricted. It consists of plagioclase felspar with pyroxene, hornblende, and magnetite, sometimes with blue opalescent quartz, and sometimes with black mica. These predominant minerals are segregated in different proportions in the different bands, some bands consisting mainly of pyroxene or hornblende, with little or no plagioclase, others chiefly of plagioclase, with small quantities of the ferro-magnesian minerals and quartz, others of plagioclase and quartz, others of magnetite. This separation of mineral constituents can hardly be attributed to mere mechanical deformation. It rather resembles the segregation layers which may be studied in intrusive sills and other deep-seated masses of eruptive material, and which are obviously due to a process of separation that went on while the igneous magma was still in a liquid or viscous condition. At the same time it is manifest that extensive dynamical changes have affected the rocks since the appearance of this original banded structure.

There is further evidence that beside the original eruptive masses, which for want of any means of discriminating their relative dates of protrusion must in the meantime be regarded as belonging to one eruptive period, other portions of igneous material have been subsequently and at successive epochs, after the first mechanical deformations, injected into the body of the original gneiss. These consist of dykes of basalt and dolerite, followed by still more basic peridotites and picrites, and lastly by emanations from a distinctly acid magma in the form of granites.

The oldest or doleritic dykes form a wonderful feature in the gneiss, from their abundance, persistence and uniformity of trend in a west-northwest direction. They have no parallel in British Geology until we reach the crowded dykes of older Tertiary time.

Throughout this remarkable complex of eruptive material, though its different portions present many features that may be compared with those of intrusive bosses and sheets belonging to later geological periods, there is no trace of any superficial volcanic manifestation. No tuffs or agglomerates or slaggy lavas have been detected, such as might serve to indicate the ejection of volcanic materials to the surface. All the phenomena of the Lewisian gneiss point to the consolidation of successively protruded portions of eruptive material at some depth within the crust.

Nevertheless it may yet be possible to show that these deep seated masses have been injected into rocks of older date and of sedimentary origin, and that they have communicated with the surface in true volcanic eruptions. I have already alluded to one limited area where various rocks exist, distinctly different from the prevalent types in the Lewisian gneiss. In the area which is traversed by the long valley of Loch Maree in western Rosshire, there occur clay-slates, fine mica schists, graphitic schists, and saccharoid limestones. These rocks remind us of some of the prevalent members of a series of metamorphosed sediments. The minerals enclosed in the marbles are just such as might be expected in the metamorphic aureole of a granite boss, piercing limestone. But the relations of this group of rocks to the ordinary gneiss of the region are not quite so clear as could be desired, though they seem to point to these rocks being surrounded by and enclosed within the gneiss.

The detailed field-work of the officers of the Geological Survey has made known the remarkable amount of mechanical deformation which the various rock-masses composing the Lewisian gneiss have undergone. These rocks have been compressed, crushed, and drawn out, until what were originally mas-

sive crystalline protrusions have been converted into perfect schists. The dykes of dolerite have been transformed into hornblende-schists and the granitic pegmatites have been reduced to a kind of powder which has been rolled out so as to simulate the flow-structure of a lava. There is evidence that most, if not all, of this dynamical change was effected long before the deposition of the Torridonian series, for the latter rests in nearly horizontal sheets, with a strong unconformability upon the crushed and sheared gneiss.

Torridon Sandstone. This group of rocks covers only a limited area in the north-west of Scotland, but it must once have spread over a far more extensive region. It reaches a thickness, as I have said, of 8,000 or 10,000 feet, and consists almost wholly of dull, purplish-red sandstones, often pebbly, and bands of conglomerate. Dark grey shales, already alluded to as occurring towards the base of the series, are repeated also in the highest visible portion, and have yielded tracks of what seem to have been annelids and casts of nail-like bodies which may have been organic. I have said that the Torridonian deposits which were classed by Murchison as Cambrian, have been proved by the discovery of the *Olenellus* zone in an unconformable position above them, to be of pre-Cambrian age. Except along the line of disturbance to which I shall immediately refer, these strata are quite unaltered. Indeed, in general aspect they look as young as the old red sandstones with which Hugh Miller identified them. It is at first hard to believe that such flat undisturbed sandstones are of higher antiquity than the very oldest Palæozoic strata which are so generally plicated and cleaved.

The interval of time between the deposition of the Torridon Sandstone and of the overlying Cambrian formations must have been of enormous duration, for the unconformability is so violent that the lowest Cambrian strata, not only transgressively overspread all the Torridonian horizons, but even lie here and there directly on the old gneiss, the whole of the intervening thick mass of sandstone having been there removed by previous denudation. At Durness, in the north of Sutherland, about 2000 feet of

Cambrian (possibly in part Lower Silurian) strata can be traced, the lower portion consisting of quartzites, the central and upper parts of various limestones, sometimes abundantly fossiliferous. Nowhere else in the north of Scotland can so thick a mass of early Palæozoic rocks be seen. Elsewhere the limestones have been in large measure replaced by a complex group of schistose rocks which rest upon the Cambrian strata, and like them dip, generally at gentle angles, towards the east. It was the opinion of Murchison, and was commonly admitted by geologists, that these overlying schists represented a thick group of sediments, which, originally deposited continuously after the limestones, had been subsequently altered into their present condition by regional metamorphism. They were variously named the "Eastern schists," the "younger gneiss," the "gneissose and quartzose flagstones." Nicol, who at first shared the general opinion regarding them, afterwards maintained that they did not belong to a later formation than the limestones, but were really only the old gneiss, brought up again from beneath by enormous dislocations and over-thrusts. We now know from the labors of Professor Lapworth and the officers of the Geological Survey, that Murchison and Nicol had each seized on an essential part of the problem, but that both of them had missed the true solution. Murchison was in error in regarding his younger gneiss as a continuous sequence of altered sedimentary rocks conformably resting on the Cambrian (or to use his terminology, Lower-Silurian) formations. But he sagaciously observed the coincidence of dip and strike between the schists and sedimentary rocks below them and inferred that this coincidence, traceable for many leagues, proved that the metamorphism which had given these schists their structure must have taken place after the deposition of the Durness limestones. Nicol, on the other hand, with great insight recognized that there was no continuous sequence above those limestones, but that masses of the old gneiss had been thrust over them by gigantic faults. But he failed to see that no mere faults would account for the coincidence between the structural

lines just referred to in the Cambrian strata, and in the overlying schists, and that the general tectonic structures and lithological characters of the eastern schists differed in many respects from those of the Lewisian gneiss.

The problems in tectonic geology presented by the complicated structures of the northwest of Scotland have been ably worked out by the officers of the Geological Survey, to whose report in the *Quarterly Journal of the Geological Society* for 1888, I would refer for full details. It has been shown that, besides stupendous dislocations and horizontal displacements, the rocks have been cut into innumerable slices which have been driven over each other from the eastward, while at the same time there has been such a general shearing of the whole region that for many hundreds of square miles the original rock-structures have been entirely effaced, and have been replaced by new divisional planes, which, when they approach the underlying Cambrian strata, are roughly parallel with the bedding planes of these strata.

In this region, therefore, we have striking proofs of a stupendous post-Cambrian regional metamorphism. But there is still much uncertainty regarding the geological age of the rocks which have been affected by it. There can be no doubt that large masses of the old gneiss, torn up from below, have been thrust bodily westward for many miles, and are now seen with their dykes and pegmatites resting on the Durness limestones and quartzites. It is equally certain that in other districts huge slices of the Torridon sandstones have been similarly treated. But where all trace of original structure has disappeared, we have, as yet, no means of definitely determining from what formation the present eastern schists have been produced. The ordinary gneissose and quartzose flagstones do not appear to me to be such rocks as could ever be manufactured by any chemical or mechanical process out of the average type of Lewisian gneiss. I have long held the belief that they were originally sediments, but whether they represent altered Torridon Sandstone, or some clastic formations which may have followed the

Durness limestones, but which have been everywhere and entirely metamorphosed, remains for future discovery. For my present purpose, it is sufficient to observe that, in the meantime, as we can not be sure of the origin of most of the rocks, which, between the West Coast and the line of the Great Glen, have been subjected to a gigantic post-Cambrian regional metamorphism, it seems safest to exclude them from an enumeration of the pre-Cambrian rocks of Britain.

Dalradian. East of the line of Great Glen, which cuts the Scottish Highlands in two, another group of crystalline schistose rocks is largely developed. It consists mainly of what were undoubtedly originally sedimentary deposits, though they are now found in the form of quartzites, phyllites, graphitic schists, mica-schists, marbles, and various other foliated masses. With them are associated numerous eruptive rocks, both acid and basic, sometimes still massive and easily recognizable as intrusive, sometimes more or less distinctly foliated and passing into different gneisses, hornblende-schists, chloritic-schists, etc. Though it is not always possible in such a series of metamorphic rocks to be certain of any real chronological order of succession, those of the Highland tracts have now been mapped in detail over so wide an area, that we are probably justified in believing that a definite sequence can be established among them. These masses must be many thousand feet thick. Their succession and association of materials are so unlike those of any of the known older Palæozoic rocks of Britain, that they can hardly be the metamorphosed equivalents of any strata which can be recognized in an unaltered condition in these islands. Some traces of annelid casts have been found in the quartzites, but otherwise the whole series has remained entirely barren of organic remains.

What then is the age of this important series? I must confess that in the meantime I can give no satisfactory answer to this question. I have proposed, for the sake of distinction and convenient reference, to call these rocks "Dalradian." Murchison supposed them to be a continuation of his Durness quartzites,

limestones, and "younger gneiss." His belief may still prove to be in some measure well founded. But at present we have no means of deciding whether the quartzites and limestones of the Central Highlands are the more altered equivalents of the undoubtedly Cambrian strata of the north-west. It is possible that in the vast mass of metamorphosed rocks constituting the wide stretch of country from the northern headlands of Aberdeen to the south-western promontories of Argyllshire, there may be portions of the old Lewisian gneiss, tracts of highly altered Torridon sandstone, belts of true counterparts of the Cambrian quartzites and limestones of Durness, and, what should not be forgotten, considerable portions of some later sedimentary series which may have followed these limestones, but which, by the great dislocations already referred to, have disappeared from the north-west of Scotland. We are gradually learning more of these rocks, as the detailed mapping of them by the Geological Survey advances, and when the ground on either side of the Great Glen is surveyed, it may be possible to speak with more certainty regarding their true geological relations.

A glance at a geological map of the British Isles will show that the metamorphic rocks of the south-western Highlands of Scotland are prolonged into the north of Ireland, where they spread over a region many hundred square miles in extent. They retain there the same general character and present the same difficult problems as to their true stratigraphical relations. Quite recently, however, a new light seems to have arisen upon these Irish rocks. My colleagues on the Irish Branch of the Geological Survey have detected several detached areas of coarse gneisses, which in many respects resemble parts of the Lewisian gneiss of north-west Scotland. In some cases these areas lie amidst or close to "Dalradian" rocks, but with that obstinacy, which so tries the patience of the field-geologist, they have persistently refused to disclose their true original position with regard to these. Some fault, thrust-plane, tract of boulder-clay or stretch of bog is sure to intervene along the very junction-line where the desired sections might have been looked for.

There can be little doubt that a strong unconformability exists between them. A close examination of the ridge of old gneiss in Tyrone and Fermanagh showed me that though the actual basement-beds of this Dalradian series could not be seen resting on the coarse gneiss, the lithological character, and tectonic arrangement of this series are only explicable on the supposition of a complete discordance between it and the gneiss. As these two groups of rock have never been found in close proximity in Scotland, and as the determination of the true age of the Dalradian series is a question of such great stratigraphical importance in the general mapping of the United Kingdom, I requested Mr. A. McHenry, of the Geological Survey of Ireland, to continue the tracing of the mutual boundaries of the old gneiss of the Ox Mountains and the Dalradian series in County Mayo. He informs me that he has found in that series a conglomerate full of blocks of the old gneiss, and resting in one locality apparently unconformably upon it. If this observation is confirmed it will finally set at rest the relative position of the coarse massive gneiss and some portion, at least, of the Dalradian series. Of course there is no absolute proof that the coarse gneisses of Ireland are really the equivalents of the Lewisian masses which they so closely resemble. But there is a strong presumption in favor of their identity.

In England and Wales many detached areas of rock have been claimed as pre-Cambrian, and successive formations have been classified among them. I have already dealt in part with this question, and without attempting here to review the voluminous literature of the subject, I will content myself with stating briefly what seems to me to have been established on good evidence.

There can not, I think, be now any doubt that small tracts of gneiss, quite comparable in lithological character to portions of the Lewisian rocks of the north-west of Scotland, rise to the surface in a few places in England and Wales. In the heart of Anglesey, for example, a tract of such rocks presents some striking external or scenic resemblance to the characteristic

types of ground where the oldest gneiss forms the surface in Scotland and the west of Ireland. In the Malvern Hills another small knob of somewhat similar material is obviously far more ancient than the Cambrian rocks of that locality. There may possibly be still some further exposures of similar rocks in the south of England, as for instance in southern Cornwall. In Anglesey a series of schists, quartzites and limestones has been included by Mr. J. F. Blake with the coarse gneiss above referred to, and a thick higher group of slates in what he terms the "Monian" system. These schists, quartzites and limestones present a close resemblance to the Dalradian series of Scotland and Ireland, and the quartzites, like those of the Highlands, contain worm-burrows. The coarse gneiss, as I have said, may be compared in general character with parts of the Lewisian rocks, so that we seem to have here, as in Ireland, two groups of schistose rocks, and both of these must be much older than the unaltered Cambrian strata which lie above them.

Along the eastern borders of Wales, there is an interrupted ridge of igneous rocks which were originally supposed to have broken through the older Palæozoic formations, but which now, owing mainly to the labors of Dr. Callaway and Professor Lapworth, are shown to be older than the base of the Cambrian system. These rocks consist of spherulitic and perlitic felsites, with volcanic breccias and tuffs. They are undoubtedly older than the *Olenellus* zone. Though the evidence is not quite satisfactory, they may not impossibly lie at the base of a vast mass of sedimentary rocks forming the ridge of the Longmynd. In that case the whole of the Longmynd succession with the volcanic group at its base must be pre-Cambrian and lie unconformably below the *Olenellus* zone. Dr. Callaway has proposed the name "*Uriconian*" for this volcanic group, while the sedimentary series has been termed "*Longmyndian*." On the supposition that the unconformability is established, there would here be a vast mass of stratified and partly erupted material forming a pre-Cambrian formation. Whether in that case any portion of this English series is the equivalent of the Torridonian rocks of

Scotland remains to be determined. The north-western part of the Longmynd ridge is made of red sandstones and conglomerates, which certainly resemble the Torridonian rocks of Ross and Sutherland.

At the base of the Cambrian rocks in Wales, Dr. Hicks has described a marked volcanic series under the name of "Pebidian," which he claims as pre-Cambrian, alleging that it is separated from the Cambrian system by an unconformability, and a band of conglomerates. I have carefully studied the evidence on this ground, and have come to the conclusion that there is no unconformability at the line in question, but that the ordinary Cambrian strata graduate downwards into the volcanic group and can not be disjoined from it. I therefore regard the so-called "Pebidian" as merely marking the duration of a volcanic period in early Cambrian time.

It will thus be seen that according to my view the unmistakably pre-Cambrian rocks of Britain consist of, first and oldest, the Lewisian gneiss; second, the Torridonian sandstones and conglomerates. The Uriconian and Longmyndian formations may prove to be in part or in whole equivalents of the Torridonian. The Dalradian rocks have not yet had their position determined. They may possibly mark a distinct pre-Cambrian series, but it seems quite as probable that they are only a metamorphic complex in which Archæan, Torridonian and Cambrian, or even Lower Silurian rocks are included.

Sir Archibald Geikie,
Director-General of the Geological Survey of Great Britain and Ireland.

ARE THERE TRACES OF GLACIAL MAN IN THE TRENTON GRAVELS?

In a paper published in *Science*, Nov. 25, 1892, I undertook to study the evidence relating to paleolithic man in the eastern United States from a new point of view,—that furnished by certain recently acquired knowledge of the contents of quarries and shops where modern aboriginal flaked implements were made. It was shown that all rudely flaked forms could be sufficiently accounted for without the necessity of assuming a very rude state of culture, and that any people, paleolithic or neolithic, would in roughing out blades—the principal product of the flaking process—produce precisely these forms and in great numbers as refuse. It further appeared that the finding of these objects in sporadic cases in glacial gravels or in any formation whatsoever, could not be considered as proving or tending to establish the existence of a particular grade of stone-age culture for the region in which the formation occurs, since they may as readily pertain to a neolithic as to a paleolithic status. It was conclusively shown that no worked stone that can with reasonable safety be called an implement has been reported from the gravels, and that it is therefore clearly useless, not to say unscientific, to go on enlarging upon the evidence of an American paleolithic period and multiplying theoretic details of its culture.

I now propose to review briefly the question of the age of our so-called paleolithic implements, the questions of the *grade* of a given feature of culture and of the *age* or chronologic place of that culture being very properly treated separately, as they depend for their support upon distinct classes of evidence. During the past summer, 1892, certain important items of new evidence have been discovered bearing upon the question of the

occurrence or non-occurrence of rudely flaked stones or of any artificial objects whatsoever in the normal gravels of the Delaware Valley, and it therefore becomes necessary to examine somewhat critically such of the published evidence as seems to be seriously affected by these recent observations.

It may be stated in beginning that no one disputes the glacial age of the Trenton gravels. The question to be discussed is simply this,—is the evidence satisfactory that works of art have been found in these gravels? Nothing else need be asked or answered. I do not take up this subject because I love controversy; disputation is really most distasteful to me. It happens that under the Bureau of Ethnology of the Smithsonian Institution I have been assigned to the work of making a survey of the archeology of the Atlantic coast region in which large areas, especially in states south of Mason and Dixon's line, remained almost untouched by investigators, and two years have been consumed mainly in these southern areas. But there are questions that refuse to be confined to definite geographic limits, and evidence secured in one section is sometimes found to bear so directly and forcibly upon problems pertaining primarily to other sections that the student of these problems must perforce become a free lance, and unhesitatingly enter any province promising results of value, howsoever fully occupied it may be by other investigators. One of the most interesting and important questions growing out of the study of American archeology has, as we have seen, arisen in the Delaware Valley, and the turn taken by some of my work in the south and west is such that I cannot pass this question by without consideration. The necessity of taking up the subject of glacial man became more and more apparent as the years passed on, and people continued to say to me, "You must go to Trenton; we are not satisfied with the present status of the question there; the evidence arrayed in favor of the theory of a paleolithic gravel man needs critical examination."

The difficulty of taking up and re-examining evidence, of which the record only remains, is, however, very great, since in

most cases the evidence rests upon or consists of field observations, and these cannot be recalled or repeated, and there is absolutely no means of testing directly the value of what is recorded. One may seek either to verify or to discredit the promulgated theories, but years of search may fail to produce a single new item of evidence bearing decisively upon the subject. It is possible that at one period numerous finds of implements should be reported from certain portions of the gravels, and that afterwards the whole remaining body of these formations should be worked over and searched without securing a trace of art; yet this latter evidence, being negative, need not necessarily be considered sufficient to overturn the original positive evidence if that happens to be of a high class. There is not the least doubt, however, that positive evidence may be so impaired by various defects and inconsistencies, that, unsupported by renewed and well verified observations, it will finally yield to the negative forces; and if the theories of a gravel man in the eastern United States, howsoever fortified by accumulated observations, are not really properly supported in every way, they are bound in time to fall to the ground. All I can reasonably hope to do now is to have the evidence relating to glacial man placed on trial, and so fully examined and cross-examined that those who accept gravel man need not longer do so blindly without knowing that there are two sides to the question, and those who do not accept him may know something of the reasons for the belief that is in them.

The evidence employed to prove the presence of a race of men in the Delaware Valley in glacial times is confined almost wholly to the alleged discovery of rude implements in the glacial gravels. Practically all the evidence has been collected by Dr. C. C. Abbott, and upon his skill as an observer, his faithfulness as a recorder, his correctness of judgment and his integrity of character, the whole matter stands. Many visitors, men of high repute in archeology and geology, have visited the site, but the observations made on such occasions appear not to have been of a nature to be of great value in evidence, the finds being doubt-

ful works of art or not having properly established relationships with the gravels in place. In the discussion of gravel man in eastern America a wide range of objects and phenomena has been considered, but the real evidence, upon which the theory of an ancient race and a peculiar culture must depend, is furnished by a hundred pieces—more or less—of rudely flaked stones said to have come from the gravels in place. And now what can be said with reference to this series of flaked stones further than that they are reported by the collector to have been found in the gravels at definite stated depths? I have elsewhere shown that they are not demonstrably implements in any case, that they are identical in every respect with the quarry-shop rejects of the American Indian, that they do not closely resemble any one of the well established types of European paleolithic implements, and that they are not a sufficient index of a particular stage of culture. I shall now present such reasons as there may be for the belief, held by many, that they were not really found in the undisturbed glacial gravels.

It is generally understood that the earliest reported gravel finds of importance were made on the banks of Assanpink creek within the city limits of Trenton, where the gravels to a thickness of twenty feet or more were exposed in a railway cutting. Later the river bluff near the lower end of the city, where the gravels were exposed to a depth of from twenty-five to forty feet, yielded large numbers. These two sites, so far as I can learn, furnished at least three-fourths of the finds in place. Other specimens were found singly in slight natural exposures, and in excavations for cellars, sewers, etc., at various points within the city limits.

The river bluff was for a considerable period the favorite hunting ground of the searchers for rudely flaked stones, and many specimens were collected. The gravels were exposed in a steep, nearly straight bank, several hundred yards in length, the base of which was washed by the river. There can be no question that Dr. Abbott and others have found shaped objects of various classes upon and in the face of this river bluff, and

the visitor to-day, although the bluff is now buried almost completely under city refuse, will hardly fail to find some rudely flaked form in the deeper gullies or upon the narrow river bank or beach at the base. Dr. Abbott explicitly states[1] that he obtained certain of these specimens from the gravel outcrops, and that they were not in talus formations, but in undisturbed deposits. How then is it possible to do otherwise than accept these statements as satisfactory and final?

Very recently, however, fortunate circumstances have brought the evidence furnished by this site again within our

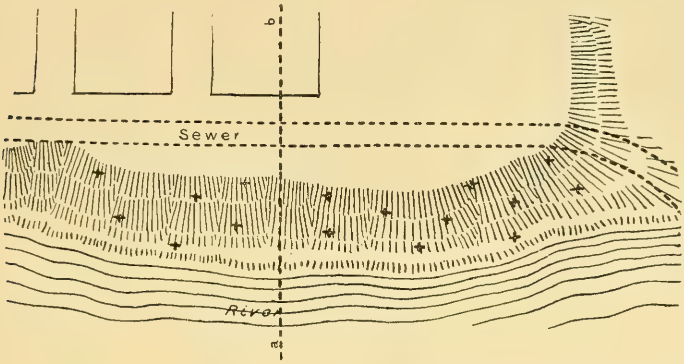

FIG. 1. Sketch map of the Trenton bluff, showing the relation of the sewer trench to the "implement" yielding slope. . . . a–b section line, FIG. 2.

reach, thus enabling us to re-open the discussion under favorable conditions. What I had for some time desired to do in this case was, what I had already done at Piny Branch, D. C., and at Little Falls, Minn., to open a trench into the face of the bluff, and thus secure evidence for or against the theory of a gravel man. This measure was, however, rendered impracticable by the occupation of the bluff margin by a city street; but it happened last summer that the city authorities, desiring to improve the sanitary condition of the city, decided to open a great sewer through this very bluff to get a lower outlet to the river. A trench twelve feet wide and some thirty feet deep, the full depth

[1] Abbott, C. C. Primitive Industry, pp. 493-510.

of the exposed gravels, was carried along the bluff just inside of its margin, opening out into the river at the point where the bluff turns toward the north-east. It was a trenching more complete and more satisfactory than any of which I had ever dreamed. At no point for the entire length of the bluff did the excavation depart more than forty feet from the line of the terrace face — from the upper margin of the slope upon which such plentiful evidence of a supposed gravel man had been obtained. The accompanying map and section, Figs. 1 and 2, will indicate

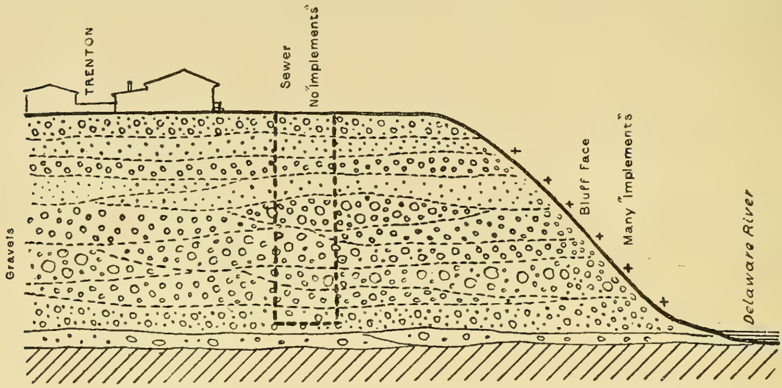

FIG. 2. Sections made by the river and by the sewer, the former yielding many "implements," the latter yielding none.

the location of the trench, and show the exact relations of the natural and artificial exposures of the gravels.

I made several visits to the place, descended frequently into the great cut and examined the gravels and their contents with the utmost care, but without securing a trace of art. Recognizing the vital importance of utilizing to the fullest extent this opportunity of testing the art-bearing nature of the gravels at this point, I resolved to undertake a systematic study of the subject. Summoning my assistant, Mr. William Dinwiddie, from his field of operations in the South, I had him spend upwards of a month at the great trench, faithfully watching the gravels as they were exposed. Mr. Dinwiddie had worked three years under my personal direction, and had helped open

upwards of twenty trenches through similar gravel deposits, and was therefore well qualified for the work. Prof. W. J. McGee, Prof. R. D. Salisbury, Dr. Stewart Culin and Dr. Abbott also visited the place one or more times each. Relics of art were found upon the surface and in such portions of the talus as happened to be exposed, but nothing whatever was found in the gravels in place, and the search was closed when it became fully apparent that the case was hopeless.

It may be claimed that the conditions under which gravels are exposed in trenching as it progresses, are not as favorable for the collection of enclosed relics as where exposed by natural processes of weathering. This is true in a certain measure, as specimens may be obscured by the damp clinging sand which forms the matrix of the gravels. This, however, would interfere but little with the discovery of large flaked stones, such as we were led to expect in this place, and this slight disadvantage in detecting shaped pieces in fresh exposures is more than overbalanced by the treachery of weathered surfaces which often give to intrusive objects the appearance of original inclusion. The opportunity for studying the gravels in all their phases of bedding, composition and contents, was really excellent, and no one could watch the constantly renewed exposures hour after hour for a month without forming a most decided notion as to the implement bearing qualities of the formation. Not the trace of a flaked stone, or of a flake or artificial fragment of any kind was found, and we closed the work with the firm conviction that the gravels exposed by this trench were absolutely barren of art. But Dr. Abbott claims to have found numerous implements in the bluff face a few feet away and in the same gravels. If this is true, the conditions of glacial occupation of this site must have been indeed remarkable. It is implied that during the whole period occupied by the melting of the ice sheet within the drainage of the Delaware valley the hypothetical rude race lived on a particular line or zone afterwards exposed by the river to the depth of 30 feet, leaving his strange "tools" there by the hundreds, while another line or zone, not more than forty feet away

at most, exposed to the same depth by an artificial trench, was so avoided by him that it does not furnish the least memento of his presence. One vertical slice of the gravels twelve feet thick does not yield even a broken stone, while another slice not probably one-half as thick, cut obliquely through the gravels near by, has furnished subject-matter for numerous books and substantiation for a brace of theories. That no natural line of demarcation between the two section lines is possible, is shown by the fact that the formations are continuous, and that the deposits indicate a constant shifting of lines and areas of accumulation; thus it was impossible for any race to dwell con-

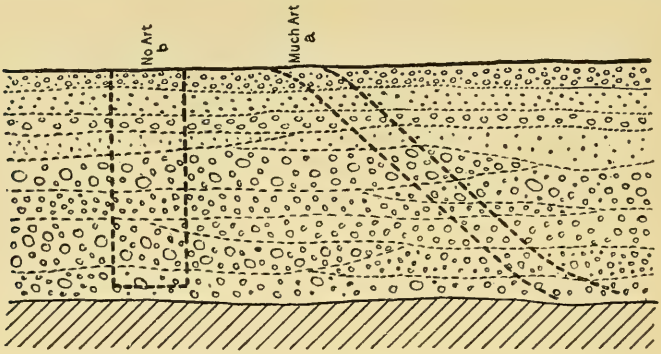

FIG. 3. *a*, Reputed "implement" producing zone of the river front. *b*, Barren zone of sewer.

tinuously upon any spot, line or plane. This is well shown in the section, Fig. 3, which gives the relations of the art-producing section of Dr. Abbott to the non-art-producing section of the sewer. The gravels were laid down entirely irrespective of subsequent cutting, natural or artificial; yet we are expected to believe that a so-called gravel man could have resorted for a thousand years to the space *a*, leaving his half shaped or incipient tools at all stages of the gravel building from base to top, failing entirely to visit a neighboring space *b*, or to leave there a single flake to reward the most faithful search. It is much easier to believe that one man should err than that a guileless race should thus conspire with a heartless nature to accomplish such extraordinary

results. The easier explanation of the whole matter is that the objects found by Dr. Abbott were not really in the gravels, but that they are Indian shop-refuse settled into the old talus deposits of the bluff, and that his eager eyes, blinded by a prevailing belief in a paleolithic man for all the world alike, failed to observe with their wonted keenness and power.

But this case does not stand alone. The first discoveries of supposed gravel implements are said to have been made when the Pennsylvania Railway opened a road bed through the creek terrace on the site of the present station. At first numerous specimens of rudely flaked stones were reported, and the locality became widely known to archeologists, but the implement bearing portions of the gravels—and this is a most significant fact—were limited in extent, and the deposit was soon completely removed, the horizontal extension containing nothing. At present there are excellent exposures of the full thickness of the gravels at this point, but the most diligent search is vain, the only result of days of examination being a deep conviction that these gravels are and always were wholly barren of art.

It thus appears that here as well as upon the river front, the works of art were confined to local deposits, limited horizontally but not vertically, and a strong presumption is created that the finds were confined to redistributed gravels settled upon the terrace face in the form of talus. Dr. Abbott states that "at that point where I gathered the majority of specimens there is a want of stratification."[1] It is well known that such rearranged deposits are often difficult to distinguish from the original gravels. In trenching an implement producing terrace at Washington—where the conditions were probably quite similar to those at the Trenton railroad station—I passed through eighty feet of redistributed talus gravels before encountering the gravels in place, and so deceptively were portions of these deposits reset that experts in gravel phenomena were unable to decide whether they were or were not portions of the original formation

[1] Abbott, C. C. 10th Annual Report of the Peabody Museum, p. 41.

(cretaceous). The question was finally settled by the discovery of artificially shaped stones in and beneath the deposits.

Again, an implement bearing deposit of gravel was recently discovered by the late Miss F. E. Babbitt at Little Falls, Minnesota, and sufficient (a very little) digging was done to satisfy the discoverer, and all paleolithic archeologists as well, that the objects were really imbedded in the glacial gravels. In the summer of 1892 I visited the place and carried a trench twenty feet horizontally into the terrace face on the "implement bed" level before encountering the gravels in place. The talus deposits were several feet thick, and were of such a nature that their true character could not be determined without careful and extensive trenching. The whole talus deposit was here well stocked with Indian quartz quarry-shop rejects, which were as usual of paleolithic types, and it was but natural that Miss Babbitt's conclusions, although based as they necessarily were upon inexpert observations, backed by such well known "types" of "implements" should be unhesitatingly accepted by believers.

The occurrence of these telling examples of the deceptive appearance of re-set gravels would seem to justify and emphasize the conviction created by a critical examination of the two leading so-called paleolithic sites at Trenton, that Dr. Abbott, notwithstanding his asseverations to the contrary, has been deceived. Very strong support, it seems to me, is given to this conclusion by the recently published opinion of the late Dr. H. Carvill Lewis, a glacialist familiar with the Trenton region, and with the work of Dr. Abbott at the period of his paleolithic castle building. Dr. Lewis is reported to have maintained before an open meeting of the Academy of Science in Philadelphia "that what Dr. Abbott believed to be undisturbed layers (of gravel) were those of an ancient talus."[1] This remark may refer to both the main sites—the one at the railroad station and the other at the river front—or possibly only to the former. I have also heard it stated that that eminent scholar, Dr. Leidy, who must have had ample opportunities of

[1]Brinton, D. G., Science, Oct. 28, p. 249.

forming correct opinions upon the subject, held pretty much the same views of Dr. Abbott's finds.

To make the above criticism entirely clear, a few words of explanation of talus phenomena may be added. As a river cuts its channel deeper and deeper into deposits of gravel a section is gradually exposed, but the gravels break down readily under

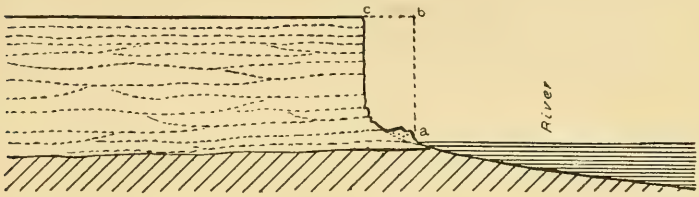

FIG. 4. A freshly formed gravel bluff.

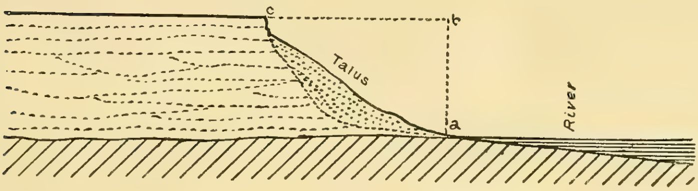

FIG. 5. Early stage of talus formation.

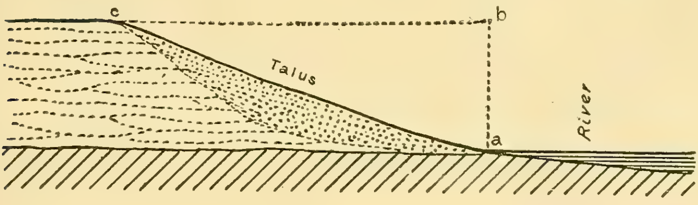

FIG. 6. An ancient talus.

atmospheric influences and the exposed face does not retain a high angle. The upper part crumbles and descends toward the base, there to rest against the slope or to be carried away by the stream. A supposititious case will be convenient for illustration. A gravel terrace twenty feet in height is encroached upon by the

river at high water and undermined, and the face breaks down vertically, leaving an exposure as illustrated in Fig. 4. In a very short time the upper portions become loosened and fall below, giving a steep slope as seen in Fig. 5. The process goes on with gradually decreasing rapidity, and if the river does not again encroach seriously, a practically stable slope is reached, as shown in Fig. 6. Such a talus may be hundreds or even thousands of years old, but there is rarely any means of determining its exact age. If the gravels are homogeneous in character, the talus will simulate their normal condition so completely that the distinction cannot be made out in ordinary gullies or by unsystematic digging. If the gravels contain varied strata the talus will be composite, and will be more readily distinguished from at least portions of the material in place.

Now it is important to observe what may be the possible art contents of such a talus as that shown in Fig. 6. It may contain all objects of art originally included in that portion of the gravels represented by *a*, *b*, *c*, together with all articles that happened to be upon the surface *b*, *c*, beside such objects as may have accumulated from dwelling or shop work upon its own surface, after the slope became sufficiently reduced to be occupied for these purposes. A talus is therefore liable to contain, and in the utmost confusion, relics of all periods of occupation, supposing always that there were such periods, from the beginning of the formation of the gravel deposits down to the present moment. As a rule such a talus, if art-containing, will have a large percentage of shop and quarry-shop refuse, for the reason that the exposed gravels, and the banks and beds of rivers cutting them, furnish, as a rule, a good deal of the raw material utilized by workers in stone, and the shops in which the work was done are usually located upon the slopes and outer margins of the terraces. Although there is the possibility of very considerable age for these talus deposits, it is unlikely that any of them date back as far as the close of the glacial epoch or at all near it, for rivers change back and forth constantly, undermining first one bank and then the other, so that a very large

percentage of our talus deposits have been formed well within the historic period.

At Trenton the constantly exposed gravel banks afforded considerable argillite in bowlders, fragments and heavy masses, as well as some other flakable stones of inferior quality little used, and it is inevitable that the Indian who dwelt upon the shores of the river should have sought the workable pieces along the bluff, leaving the refuse everywhere; and it is a necessary consequence that the terrace margin, the bluff face, and the talus deposits, places little fitted for habitation, should for long distances contain no trace of any art shapes save such as pertain to manufacture. Thus are fully and satisfactorily accounted for all the turtle backs and other rude forms that our paleolith hunters have been so assiduously gathering. Nothing can be more fully apparent than that no other race than the Indian in his historic character and condition need be conjured up to reasonably account for every phase and every article of the recovered art. Mistaken interpretations of the nature of shop rejects, and the common association of these objects with redistributed gravels, are probably accountable for the many misconceptions that have arisen. Talus deposits form exceedingly treacherous records for the would-be chronologist. They are the reef upon which more than one paleolithic adventurer has been wrecked.

Relics of art attributed to gravel man have been collected, so far as I can gather from museum labels and from incidental references in various publications, from a number of sites aside from the two already referred to. These are scattered over the city, and the finds were made mostly in exposures of the gravels that remained visible for a short time only, as in street and cellar excavations and well pits. These reported finds can never be brought within the range of re-examination, and the searcher after unimpeachable testimony must content himself with placing them in the doubtful column on general principles. Urban districts are so subject to disturbance through cutting down of hills, filling in of depressions, grading of streets, digging of

foundations, cellars, sewers, wells and graves that no man can, from a limited exposure such as those producing the reported tools necessarily were, speak with certainty of the undisturbed nature of the deposits penetrated. It is doubtful if any one is justified in publishing such observations at all without serious query. Such testimony is liable to fall of its own inherent weakness, being absolutely valueless if unsupported by collateral evidence of real weight. It can only be made permanently available to science by the discovery of something unusual or unique with which to couple it, something decidedly un-Indian in character or type, as for example the two skulls now in the Peabody Museum. These objects and the antler knife-handle exhibited with them may be alluded to as the only finds so far made at Trenton, having of themselves the least potentiality as proof and these skulls and this knife-handle must yet be subjected to the rigid examination made necessary by the importance of the conclusions to be based upon them.

Something may now be said concerning the art remains upon which this discussion hinges, and upon which conclusions of the greatest importance to anthropology are supposed to depend. Let us pass over all that has been said with regard to their manner of occurrence and association with the gravels and ask them simply what story they tell of themselves. Does this story, so far as we are able clearly to read it, speak of a great antiquity and a peculiar culture, or does it hint rather at vital weaknesses in the position taken by the advocates of these ideas? We shall see. The history of the utilization of rudely flaked stones in the attempt to establish a gravel man in America has never been written, but as read between the lines of paleolithic literature, it runs about as follows: The theory of a very rude and ancient people, having a unique culture and certain peculiar art limitations, was developed in Europe many years ago in a manner well known and often rehearsed. This people was associated with the ice age in Europe, and this epoch, with its moraines and till and sedimented gravels, was found to have been repeated in America. It was the most natural thing

possible that these discoveries should carry with them the suggestion that man may have existed here as in Europe during that epoch, and that his culture was of closely corresponding grade. These were legitimate inferences and warranted the instituting of careful researches, but it was a dangerous suggestion to put into the minds of enthusiastic novices with fertile brains and ready pens. The idea was hardly transplanted to American soil before finds began to be made. The so-called "types" of European paleoliths suggested the lines upon which finds here should be made, and everything in the way of flaked stones connected directly or indirectly with the glacial gravels which had not yet been fully credited to and absorbed by the inconvenient Indian, was seized upon as representing the ancient time and its hypothetic people and culture. In the early days of the investigation the various rude forms of flaked stones, resulting from failures in manufacture, had not been studied, and were shrouded in convenient mystery, and they thus became the foundation of the new archeologic dynasty in America, the dynasty of the turtle-back. Dr. Abbott states in his first work[1] that these rude "implements" are not especially characteristic of any one locality, but seem to be scattered uniformly over the state. Specimens of every type, he says, are "found upon the surface, and are plowed up every spring and autumn; but this in no way militates against the opinion that these ruder forms are far older than the well-chipped jasper and beautifully-polished porphyry stone-work."[2] At that stage of the investigation it was not at all necessary that a specimen should come from the gravels in place or from any given depth, since the "type" was supposed to be easily recognized and was a sufficient means of settling the question of age.

Rude "implements" were called for and they were found. The only requirements were that they should not be of well-known Indian types, that they should be rude and have some sort of resemblance to what were known as paleolithic implements

[1] Abbott, C. C. The Stone Age in N. J., Sm. Rep. 1875, p. 247.
[2] Ibid, p. 252.

abroad. Since most of these so-called gravel implements of Europe are also doubtless the rejects of manufacture resemblances were readily found. The early attempts to utilize these rejects in support of the theory, and make them masquerade creditably as "implements" with specialized features and self-evident adaptation to definite ice-age uses, now appear decidedly amusing. Gradually, however, the lines have been drawn upon this early license, and it is to-day well understood by all careful students, that since the rude forms are so often repeated in modern neolithic refuse, the only reliable test of a gravel "implement" is its occurrence in the gravels in place. That a particular "implement," said to have been obtained from the gravels, is of "paleolithic type," does not in the least strengthen its claims to being a *bona fide* gravel implement; nor does its easy assignment to a "type" give any additional value to the collector's claim that the gravels said to contain it are implement bearing. The very names, "rude implement," "paleolithic implement," etc., carry with them a certain amount of mysterious suggestion; one thinks of unique, significant shapes and of strange, archaic uses. At their mere mention, the great ice sheet looms up with startling realism, and the reindeer and the mighty mammoth appear upon the scene. The reader of our paleolithic literature is led to feel that these antiquated objects carry volumes of history in their worn and weather-beaten faces, but this is all the figment of fertile brains. These objects have without exception the appearance of the most commonplace every-day rejects of manufacture without specialization and without hidden meaning. They tell of themselves no story whatsoever, save that of the oft-repeated failure of the aboriginal blade maker in his struggle with refractory stones. This will be shown with greater clearness farther on.

But the scheme does not end with the repetition of a European state of affairs. Our gravel archeologists have not been content to adopt that feature of the foreign scheme which utterly destroys the paleolithic race before a higher culture is brought upon the scene. It was thought to improve upon the

borrowed plan by allowing for a gradual development upward from the paleolithic stage, represented exclusively by a class of meaningless bits of flaked stone, through a period less rude; characterized by productions so far advanced as to be assigned to a definite use. These latter productions consist mainly of rather large and often rude blades, sometimes plain, but generally notched or modified at the broader end as if to be set in a handle, or attached to a spear or arrow shaft. These were assigned to post-glacial times in such a way as to bridge or partly bridge the great space between the glacial epoch and the present. They were separated arbitrarily from the body of the collections of the region, and referred to as probably the work of an Eskimo race. This arrangement produced a pleasing symmetry and completeness, and brought the history of man down to the beginning of the Indian epoch, which is represented by all of those forms of art with which the red man is historically associated.

Three principal periods are thus thought to be represented by the finds at Trenton; and in the arrangement of the collections these grand divisions are illustrated by three great groups of relics, which are looked upon by the founders of the scheme as an epitome of native American art and culture. By others this grouping is looked upon as purely empirical, as an arbitrary separation of the normal art remains of the historic Indian, not suggested by anything in the nature or condition of the objects, nor in the manner of their discovery.

The "Eskimo" feature of the scheme requires a more detailed examination than can be given it here. It may be stated, however, that the separation of the so-called Eskimo spear points, or whatever they may be, from the great body of associated articles of flaked stone, appears to be a highly arbitrary proceeding. That they were extensively made by the Indians is proved by the occurrence of refuse resulting from their manufacture on modern shop sites, and that they were used by the Indian, is equally apparent from their common occurrence on modern dwelling sites. The exceptionally large size of the

argellite points is readily accounted for by the nature of the material. It was the only stone of the region well adapted to the manufacture of long blades or projectile points. Jasper, quartz and flint have such minute cleavage that, save in rare cases, small implements only could be made from them. Their peculiar manner of occurrence, described at so much length by Dr. Abbott,[1] has been given undue consideration and weight. The phenomena observed may all be accounted for as a result of the vicissitudes of aboriginal life and occupation within the last few hundred years as fully and satisfactorily as by jumping thousands of years backward into the unknown.

Whatsoever real support there may be for the "Eskimo" theory, either in the published or the unpublished evidence, it is apparent that under the present system of solitary and inexpert research, the scientific world will gain little that it can utilize without distrust and danger. Whatsoever may be the final outcome—which outcome is bound to be the truth—it is clear that there is little in the present evidence to warrant the separation of a "paleolithic" and an "Eskimo" period of art from that of the Indian.

That the art remains of the Trenton region are essentially a unit, having no natural separation into time, culture or stock groups, is easily susceptible of demonstration. I have already presented strong reasons for concluding that all the finds upon the Trenton sites are from the surface or from recent deposits, and that all may reasonably be assigned to the Indian. A find has recently been made which furnishes full and decisive evidence upon this point. At Point Pleasant, on the Delaware, some twenty-five miles above Trenton, there are outcrops of argillite, and here have been discovered recently the shop sites upon which this stone was worked. There are two features of these shops to which the closest attention must be given. The first is that they are manifestly modern; they are situated on the present flood plain of the Delaware, and but a few feet above average water level, the glacial terrace here being some forty or

[1] Abbott, C. C. Popular Science Monthly, Dec., 1889.

fifty feet in height. These shops, therefore, represent the most modern phases of aboriginal industry, and may have been occupied at the coming of William Penn. The second point is that every type of flaked argillite found in the Trenton region, associated with the gravels or otherwise, is found on this site. It was to a certain extent a quarry site, for the great masses of argillite brought down by the floods were here broken up and removed from the river banks or bed. It was a shop site, for here the articles, mainly blades, were roughed out, and it was also a dwelling place—a village site—where all the specialized forms of flaked stones made from the blades were prepared for use. Here are found great numbers of the rude failures, duplicating every feature of the mysterious "paleolith" with which our museums are stocked, and exhibiting the same masterly quitting at just the point "where no further shaping was possible."[1] Here we see the same boldly manipulated "cutting edge," the "flat bottom" and "high peak," and the same mysteriously weathered and disintegrated surfaces, so skillfully made, by a nice balancing of accidents,[2] to tell the story of chronologic sequence in deposition.

Beside the failures, we have here, as on other quarry shop sites, the evidence of more advanced work, the wide, thick, defective blades, and many of the long, thin blades broken at or near the finishing point. Here, too, just back of the roughing-out shops, are the dwelling sites from which many specialized forms are obtained. The "Eskimo" type is fully represented as well as the ordinary spear point, the arrow point, and the perforator of our Indian. There is not a type of flaked argillite known in the Delaware valley that may not be duplicated here on this modern Indian site, and this has been known by local archeologists for years. Why so little has been said about the matter is thus explained. Dr. Abbott, in 1890, discovering this site, and finding "typical paleolithic implements" (the ordinary ruder forms of rejects) among the refuse, was so entirely at a

[1] Abbott, C. C. Smithsonian Report, 1875, p. 248.

[2] Ibid. Primitive Industry, p. 487.

loss to explain the occurrence that he felt compelled to again "take up the examination of the gravel deposits of the valley of the Delaware" with the hope of "finally solving the problem."[1] The true conditions would have been at once apparent to any one not utterly blinded by the prevailing misconceptions.

The entire simplicity of the archeologic conditions in the Delaware valley may be further illustrated. Had William Penn paused in his arduous traffic with the tawny Delawares, and glanced out with far-sighted eyes from beneath the pendant branches of the great elm at Shackamaxon, he might have beheld an uncouth savage laboriously fabricating rude ice age tools, making the clumsy turtle-back, shaping the mysterious paleolith, thus taking that first and most interesting theoretical step in human art and history. Had he looked again a few moments later he might have beheld the same tawny individual deeply absorbed in the task of trimming a long rude spear point of "Eskimo" type from the refractory argillite. If he had again paused when another handful of baubles had been judiciously exchanged, he would have seen the familiar redskin carefully finishing his arrow points and fitting them to their shafts preparatory to a hunting and fishing cruise on the placid Delaware. Thus in a brief space of time Penn might have gleaned the story of the ages — the history of the turtle-back, the long spear point and their allies — as in a single sheaf. But the opportunity was wasted, and the heaps of flinty refuse left upon the river bank by the workmen were the only record left of the nature of the work of that day. Two hundred years of aboriginal misfortune and Quaker inattention and neglect have resulted in so mixing up the simple evidence of a day's work, that it has taken twenty-five years to collect the scattered fragments, to sift, separate and classify them, and to assign them to theoretic places in a scheme of culture evolution that spans ten thousand years.

Yet is there really nothing in it all, in the theories, the

[1] Abbott, C. C. Annual Report of the Curator of the Museum of American Archeology, University of Pennsylvania. No. 1, p. 7.

observations, the collections and the books? Do I speak too positively in condemnation of the results of years of earnest investigation? Perhaps so, but the voluminous testimony is so overloaded with inaccuracies, the relics of unscientific method and misleading hypotheses, that every item must be sharply questioned; and the conclusions reached so far overstep the limits warranted by the evidence, that heroic measures alone can be effectual in determining their exact value. If, as many believe, vital errors have been embodied in the evidence presented by the advocates of the theory, it is impossible to state the case too strongly. Error once fully absorbed into the literature of science has many advantages over the tardy truth; it is strongly fortified and must be attacked and exposed without fear or favor. Truth involved with it cannot permanently suffer. If the twin theories of a gravel and a paleolithic man in eastern America are to be assailed as unsound or as not properly supported, it should be done now while the originators and upholders are alive and alert to sustain their positions or to yield to the advances of truth. I do not wish to wrongly characterize or to unduly minimize the evidence brought to bear in favor of these theories. I do intend, however, to assist the world so far as possible in securing an exact estimate of all that has been said and done, and all that is to be done.

In a previous article I have examined the evidence relating to paleolithic art in the eastern United States, and have indicated its utter inadequacy and unreliability. In this paper the testimony relating to the occurrence of gravel art, in the locality most fully relied upon by advocates of the theory, has been partially reviewed and subjected to the strong light of recent observations. It is found that the whole fabric, so imposing in books and museums, shrinks away surprisingly as it is approached. The evidence furnished by the bluff face and by the railway cutting, the two leading sites, is fatally weakened by the practical demonstration of the fact that the gravels proper are at these points barren of art remains. In endeavoring to naturalize an immigrant hypothesis, our gravel searchers, unac-

quainted with the true nature of the objects collected and discussed, and little skilled in the observation of the phenomena by means of which all questions of age must be determined, have undoubtedly made grievous mistakes and have thus misled an expectant and credulous public.

The articles themselves, the so-called gravel finds, when closely studied are found to tell their own story much more fully and accurately than it has heretofore been read by students of archeology. This story is that the art of the Delaware valley is to all intents and purposes a unit, that there is nothing unique or especially primitive or ancient and nothing un-Indian in it all. All forms are found on demonstrably recent sites of manufacture. The rude forms assigned by some to glacial times are all apparently "wasters" of Indian manufacture. The large blades of "Eskimo" type are only the larger blades, knives and spear points of the Indian, separated arbitrarily from the body of the art-remains to subserve the ends of a theory, certain obscure phenomena of occurrence having been found to give color to the proceeding. To place any part of this art, rude or elaborate, permanently in any other than the ordinary Indian category will take stronger proofs than have yet been developed in the region itself.

The question asked in the beginning, "Are there traces of glacial man in the Trenton gravels?" if not answered decisively in the negative, stands little chance, considering present evidence, of being answered in the affirmative. In view of the fact that numerous observations of apparent value have been made in other sections, there is yet sufficient reason for letting the query stand, and we may continue to cherish the hope that possibly by renewed effort and improved methods of investigation, something may yet be found in the Trenton gravels clearly demonstrative of the fascinating belief in a great antiquity for the human race in America.

The evidence upon which *paleolithic man* in America depends is so intangible that, unsupported by supposed analogies with European conditions and phenomena, and by the suggestions of

an ideal scheme of culture progress, it would vanish in thin air; and if the theory of a *glacial man* can summon to its aid no better testimony than that furnished by the examples examined in this paper, the whole scheme, so elaborately mounted and so confidently proclaimed, is in imminent danger of early collapse.

W. H. HOLMES.

GEOLOGY AS A PART OF A COLLEGE CURRICULUM.

THE demand for scientific studies as a part of the college curriculum is felt by all those who have to do with the provision of higher instruction for American youth. The reasons for this may be various, but a fundamental reason is found in the tendency among the American people in particular, and in this age in general, toward practicality in all things. Applied to education this practicality asks for a training which shall have a direct bearing upon the business of life to be followed immediately after the training period is ended. It means a differentiation of subjects and specialization in methods to adjust the education to the different functions which the students taking it are preparing for. It calls for a professional education for those who expect to become lawyers, doctors, ministers, or teachers,—a technical education for those who are to engage in the arts of the mechanical or civil engineer, or of the architect. It results not only in the establishment of colleges and universities devoted to this kind of education, but it affects the methods of the high schools and academies, and is felt down to primary schools, and on the other hand the older institutions founded on a different plan are adapted to the popular demand by the addition to the regular studies of "electives," chosen not always for their value or disciplinary studies, but because of the practical applicability of the information to be derived from them, to the business of the student.

Without discussing the relative merits of the two ideas of education, the chief contrast between them may be found in the character of the results sought. The knowledge of things and their uses is of chief importance in the practical education; the knowlege of ideas and skill in their use is the aim of the liberal education. Geology is one of the sciences which most men will at

once classify as among the practical sciences. It deals with matters of practical importance to everybody. Coal, iron, the metals, silver, gold, tin, lead, building stone, sand, clay, petroleum, and natural gas, and all geological products are essential materials of modern civilization, and a knowledge of them and of their modes and places of occurrence is one of the requisites of an education, either from the practical or the liberal point of view. So too the dynamics of atmospheric and hydraulic erosion, the agency of rivers and oceans in destruction, removal and reconstruction of geological formations have their eminently practical bearings upon the various arts of engineering. While the practical value of geology is thus evident and undisputed, it is not on this account that its importance as a part of a college course of education is urged. As a practical study geology becomes the centre of a group of studies requiring years for mastery. Chemistry and physics are primarily essential to a full understanding of the most common of geological problems. And to use geological facts and phenomena, an acquaintance with the complex methods of engineering, civil and mechanical, which again call for a thorough mastery of mathematics, is necessary. Mineralogy and petrography, metallurgy and mining engineering have each reached a stage of development entitling them to the rank of separate sciences, but the practical training of the geologist should include them all. When we add the biological sciences connected with historical geology, paleontology, zoölogy and botany, with all the laboratory and field work required for their proper study, we have a group of affiliated branches of learning requiring four or five years of continuous study after the student has learned how to study. It is plain therefore that only a specialist, one who is willing to neglect other studies, or who has previously had a liberal training, can perfect himself on the practical side in the science of geology.

But irrespective of its practical uses, as a means of training and supplementary to the ordinary studies of a college curriculum, geology is one of the most useful of the sciences of obser-

vation. It is in providing that particular training to which President Eliot has recently called attention in the *Forum* (Dec., 1892, Wherein Popular Education Has Failed), that geology can be used to such advantage. Speaking particularly of the lower education, President Eliot says it is "the judgment and reasoning powers" that particularly require attention. Their systematic development is to be attained in the four directions of "observing accurately, recording correctly, comparing, grouping and inferring justly, and expressing cogently the results of these mental operations." (p. 421.) The attainment of these ends is one of the purposes of liberal education, whether it be in the primary school or in the university. And geology, or any other science, is of value in a college course in proportion to its fitness for the exercise and development of these functions of the student. Geology may be taught without regard to these ends, and then it is valuable from the practical point of view, but when we examine it in respect of its availability as a disciplinary study we find it offering particular attractions.

Using the distinction between theory and practice, which is as old as Aristotle, geology in its theoretical aspect is more easily comprehended than is the theoretical aspect of most of the modern sciences. This arises first from the fact that the facts and phenomena are of a simple and grand nature, making it possible for the teacher to direct certain attention to the specific facts under consideration. The water of the rivers, the mud by the road side, the rocks and sands on the shore are familiar objects to all, and it is a simple matter to call attention by ordinary language to the specific facts regarding them, which, analyzed out, are to form the basis of exact ideas and scientific definition and classification. Geology is the one science among the natural sciences which may begin with the common language of the pupil, and by means of such language alone may build up ideas of precise phenomena in scientific terms. Physiography or physical geography surpasses geology proper in this particular, as the admirable work of Professor Davis is showing, and on this account it is the best introduction to geology. But

the very largeness and indefiniteness of the facts are in the way of the use of physical geography for the exercise of the finer and more exact functions of observation. The disciplinary value of classics and mathematics is to a considerable extent derived from this quality, the precision with which the words or figures kindle like ideas. So long as the object of the training is to teach the knowledge of ideas and how to use them, classics and mathematics are the simplest and purest means of developing a liberal education. The addition of sciences to the college course is not because of the usefulness of the knowledge of things thus to be gained, but because the language of the sciences is essential to call forth the observation and the exercise of the accompanying mental operations.

When it comes to dealing with the ideas associated with particular sense-observation, where form or motion can not be expressed in simple mathematical terms, language can not communicate a new idea or kindle it in another mind with precision. It is necessary by some means to recall or to present the object itself to the student. In the teaching of science this point is of great importance, and much of the unsatisfactoriness of science-teaching is doubtless due to failure to note it. No circumlocution of words can arouse in another or communicate to him the idea appropriate to a sensation he has never felt. The blind man whose eyes are opened sees men as trees walking.

In the use of science for elementary training (and the training is elementary until the student is capable of investigating and interpreting the facts and phenomena of a science directly) that science is the better which deals with objects which are simple, common and easily observed. Such is geology in some of its aspects. Every time the student walks in the country he sees the facts discussed in the text-book or by his teacher; and from attention to those with which he is already familiar he can be readily led to observe and give attention to others and to analyze those already in his mind by properly directed questions.

In the field of geology are found the ready means for the exercise and development of observation and thought. The

learner begins with ideas which every intelligent mind associates with the objects described or named, and by degrees the marks of his knowledge are increased, the relations of things are grasped, and the content of his ideas associated with the language of his science is enlarged. In the process of learning the science he has been building up his stock of knowledge of facts and phenomena, but, of more importance than that, he has learned the method of observing and of scientific thinking. He has had training in the methods of reducing the hard facts of nature to the laws of thought and practice, he has seen the method by which theoretical order is made out of the interminable confusion and complexity of natural things.

Beside this primary reason for the use of geology as a disciplinary science-study, there is a second reason arising from the symbolic nature of a large group of its facts. This aspect of the science is best seen in the historical and stratigraphical parts of geology, in which fossils are the chief data for study. The interpretation of a fossil into a species of organism, having its definite place in the elaborate classification of the zoölogist, or as an indicator of the time and place and mode of formation of the strata in which it is buried, is, to be sure, a most intricate and, at first thought it would seem, an unattractive process. But no more so, I would say, than the interpretation of a series of Greek characters. The interpretation of the Greek reveals to us the richest results of human thought and most perfect laws of human speech, and we find therefore in the analysis required the most perfect discipline of the powers of speech and language. The fossil too holds, ready to be revealed, the story of the history of the world and the laws of the evolution of the organic life of the globe, and records an inexhaustible wealth of information regarding the laws of nature. But as an instrument of intellectual discipline its great merit lies in its symbolic nature. It is this symbolic character of the classical languages and of the mathematics which fits them to be universal means of liberal training. The symbolic nature of the fossil fits it to become the exponent of training in the pure science of nature.

The fossil is a mark which stands for something, and thus, in the nature of things, it asks for interpretation. As a symbol it stimulates minute and accurate observation, and kindles close and exhaustive thought; as a symbol it leaves us the ideas it has engendered after it is lost to memory as an observation. Thus the value of its study does not depend upon the retention in the memory of the facts brought before the mind, but in the training of the mental processes required in its interpretation. The study of this branch of geology exercises and develops all the faculties which are specially exercised in any scientific investigation.

Another aspect in which it is an ideal means for such training comes from the fact that it is equally valuable at every stage of progress of the student. When first examined it means nothing to him. He knows nothing of organism, of strata, of geological time. The fossil gains meaning only as he is able to put meaning into it. The student must ask questions, and as step by step he answers his questions by more minute and wider examination, the fossil holds a fuller interpretation. His studies lead him to investigation of the whole field of nature, the rocks, the formation of deposits, the action of the elements, the conditions of life, the forms of organism, their functions and habits, the laws of growth, their adaptation to environment, the changes of events in time, the efforts of association and struggle for life, the principles of evolution and development—the migration and origin and extinction of organisms on the globe. Nothing in nature is without interest to him. Further than this the amount of good he gains is not measured by the number of fossils he studies, but by the wideness of his research. A handful of fossils from some one fossiliferous ledge may be the text for a year's study, and the methods acquired in the study may be the nucleus of a life's work. In this department of geology the possibilities for new discoveries, new developments of science are almost endless. As a single author thoroughly read develops a wealth of knowledge of the laws of language and thought, so geology may be

studied by the use of a limited set of its phenomena and become the introduction to the exhaustive study of natural science.

Another advantage attaching to geology as a science-study for the college curriculum, arises from the fact that it may be pursued deeply without the elaborate aid to the senses required in other sciences for making minute record or measurement of facts or phenomena. As in language and mathematics, it is essential to acquire a familiarity with the grammar, the dictionary and the symbols, formulas and rules of their usage before the finer training in the use of thought begins, so the vocabulary and the definitions of a science must be acquired before much use can be made of the higher discipline to be derived from scientific study. In language study this higher training comes from practice in making the minute analysis, in detecting the fine shades of meaning expressed in the literature itself. So it is important in selecting a science to be used as a disciplinary study that the facts and laws of nature with which it is concerned should be capable of clear and precise definition, and, moreover, that it should furnish a field for the study of the minute and intricate relationship existing between the different facts which are to be attained by personal inspection of the objects themselves. In most of the sciences this deeper exercise of scientific thought requires for its successful pursuit artificial aids to the common senses of observation. Chemistry must have its purified acids and reagents, test tubes, and delicate scales for measurement of weight and volume. Mineralogy must have its chemical analyses, or optical measurements so fine that microscopes of highest power are essential tools for the investigation. Physics must have the most delicate measurements of time and space and weight. Botany, for the earlier stages of study, is fully equal to geology in these respects, but its scope is much less general. Zoölogy requires dissections calling for skill in manipulation, and in other respects is ill adapted to general classes. But precision in the intellectual processes of observation and reasoning can be cultivated in the use of geological facts to their highest and widest perfection, with scarcely any

aids to the normal faculties of observation. A couple of hammers, a pocket lens, a chisel and a few pointed steel tools for revealing fossils, a tape line, compass and clinometer are the few equipments that will enable the geologist to carry his investigations to almost any degree of thoroughness.

What has already been said applies to the study of the pure science of geology either in the field or in the laboratory. There is still another use to which this, as other sciences, may be put in disciplining the college student in directions not provided for by literary or mathematical studies,—the study of man as an investigator. In the pursuit of the study of geology, the first instruction must be received in didactic form, but after the text-book and lecture stage is passed, or while it is under way consultation of the literature of the sciences is appropriate. In the use of scientific literature the critical judgment is brought under training, and the varying interpretations of well known phenomena by expert scientists suggest the prominent part which the notions already in the mind play in the interpretation of the external facts observed. The experienced geologist will recall many cases of honest report of impossible facts by men who are unable to distinguish between what they saw and the false interpretations they made of these observations. One man will report that a live toad jumped out of the middle of a solid piece of coal, when it was heated in the stove; another will swear that he saw a fossil shark's tooth taken out of a ledge of Trenton limestone. It is evident that our memory of observation is not the revival of the object producing the sensation, but of the idea we framed of the sensation at the time. The study of original descriptions of objects of nature reveals the fact that the describer uses the ideas he already has in his mind as he does the standard foot-rule in his hand for measuring that which he describes, and it is by the study of scientific literature and the comparison of views of many scientists that this highest discipline of the observational faculties is attained—the power to determine the personal equation of error for the observer, and thus see through his descriptions a truer represen-

tation of the facts than the observer himself saw. Geological literature is admirably adapted for this higher discipline, and in no field of science (I think not in astronomy itself), has wider and more comprehensive thought been applied than in geology. While other branches of science have been developed and become more narrow and special in their treatment of the facts concerned, geology still stands as the most comprehensive of all the sciences of nature.

H. S. WILLIAMS.

YALE COLLEGE, November 30, 1892.

THE NATURE OF THE ENGLACIAL DRIFT OF THE MISSISSIPPI BASIN.

It is of some importance, both to the practical work of the field and the theoretical deductions of the study, to determine the nature and amount of the drift that was carried forward in the body of the ancient continental glaciers, and brought out on their terminal slopes and at length deposited at their frontal edges, and to distinguish it from that which was pushed or dragged or rolled along at the bottom of the ice.[1] It may be helpful to indulge in a speculative discussion at the outset to prepare the way for the specific evidence and the inferences to which it leads.

Whenever a prominence of rock is overridden and enveloped by a glacier of the free-moving continental type, one of two things takes place ; either that part of the ice which passes over the summit of the prominence flows down its lee slope, carrying whatever debris it dislodges down to the rear base, and thence onward along the bottom of the ice, or else the currents which pass on either side of the prominence close in behind it before the corresponding current which passes over the summit reaches the point of their junction, in which case the summit current is forced to pass off more nearly horizontally into the body of the ice, carrying with it whatsoever debris it has dislodged from the summit of the prominence and embodied within its base. The law of the phenomena appears to be that whenever the height of the prominence is less than one-half the base, measured transversely to the movement of the ice, the summit current will follow down the lee slope ; but whenever the height of the promi-

[1] Debris, which may be imbedded in the basal layer of the ice during some part of its transportation, but which is brought down to the bottom and subjected to basal action in the latter part of its course, and ultimately becomes a part of the basal deposit, is not here included in the englacial drift.

nence is more than one-half the transverse base, the lateral currents will close in on the lee, and the summit current will flow off into the body of the ice. This simple law is, however, subject to very considerable modifications from several different sources which may be grouped under (1) differences in the friction arising from basal contact, and (2) differences of internal friction and mobility. The lateral currents will expose more surface to the sides and base of the hill and the adjoining plain, and will be more subject to conflicting currents, while, on the other hand, being deeper currents, they will presumably be more fluent. These and other qualifying conditions will go far to vitiate the application of the law, but its statement may have some value as representing a general conception of the phenomena. When the height of the prominence becomes great relative to the total thickness of the ice, the fluency of the summit current may be much reduced relative to that of the central parts of the lateral currents. When the prominence reaches the surface, blocks dislodged from it are borne away on the surface of the glacier, and constitute superglacial drift. Blocks dislodged from near the summit, but below the surface of the ice, are presumably carried onward in the upper zone of the glacier; while other blocks detached at various but sufficient heights on the side of the prominence are doubtless borne around into the lee and carried forward in the same vertical plane as the summit stream, so that there comes to be a vertical zone set with boulders moving on from the lee side of the nunatak.

Lofty ledges or plateaus, with vertical or undercut faces, furnish similar means for the lodgment of debris within the body of the ice.

In these and doubtless in other ways it appears that there came to be lodged directly within the body of the Pleistocene glaciers at some considerable distances above their bases, blocks derived from rock prominences that rose with sufficient steepness above the general surface of the country over which the ice passed. The lodgment of debris on the lateral borders of glaciers is neglected here because it has little or no applicability to

the phenomena of the upper Mississippi basin. It is also doubtful whether any prominences protruded through the ice except near the thin edge, when advancing and retreating, and these are too inconsiderable to merit attention.

It is obvious, upon consideration, that blocks detached from summits or from the sharp angles of out-jutting ledges or plateaus might suffer some glacial abrasion in the process of their dislodgment and transposition along the crest or projecting angle, but that in general such abrasion would be small, and, in most cases, nearly or quite absent. The debris so incorporated in the body of the ice would be, for the most part, angular, and, as it was brought forward in the ice, it would probably suffer very little abrasion. If it continued to move forward in the plane in which it started, descending only so much as the bottom wastage of the ice required, it would be brought out to the terminal slope of the ice sheet by virtue of the melting away of the ice above, and thence it would be carried on down the terminal slope as superglacial debris, and dropped at the frontal edge. If this be the true and full history, there would be no commingling of this englacial matter with the subglacial debris. It is evident that the englacial matter brought forward from the crest of one prominence would be intermingled with that brought forward from other prominences lying in a line with it, or lying so near it that the lateral spreading of the debris would lead to commingling. It is also clear that variations in the direction of currents would tend to the same result, so that englacial matter from different prominences of the same general region might be commingled. So also englacial material, by crevassing and by the descent of streams from the surface to the base, would be carried down to the bottom and mingled with the subglacial debris. So also blocks broken away from the base of the prominence which yielded the englacial erratics might be moved forward along the bottom parallel with the englacial material above, and lodged at any point along the line. It is therefore to be expected that the basal deposits will contain the same rock species as the englacial, but if there be no

process by which the basal material is carried upward the reverse will not be the case, and there will be a clear distinction between the englacial deposit and the subglacial deposit, in composition as well as physical state.

Not a few glacialists, however, advocate in somewhat differing forms and phases the doctrine that basal material is carried upward into the body of the glacier and at length reaches the surface, and that at the extremity of the ice this is commingled with any erratics that may be englacial or superglacial by original derivation. This doctrine appears to have had its origin in the endeavor to explain the very common fact that glacial drift has been carried from lower to higher altitudes. Erratics are often found lodged several hundred feet higher than the outcrop from which they were derived. It has never seemed to me, however, that this phenomenon necessarily was different in kind from that which takes place in the bottom of every stream; at least I have not come in contact with any instances that seemed to require a different explanation, except those connected with kames and eskers that require a special explanation in any case. We are so accustomed to view streams from above, and so accustomed to study the extinct glaciers from the bottom, that we are liable to overlook the community of some of the simpler processes involved alike in both phenomena. The dictum that water never runs up hill is measurably true of the surface currents of the ice as well as water, but it altogether fails when applied to the basal currents of either. It is probable that there is no natural stream of any length in which, at some part of its course, basal debris is not carried from lower to higher altitudes and lodged there. If the bed of any stream were made dry and the debris in it critically examined, it would be found that at numerous points the silts or sands or gravels had been carried from the bottom of some basin in its bed to the higher rim or bar or reef that bordered it on the down-stream side. So I conceive that, on a grander scale, the natural result of the flow of the basal ice of a continental glacier over the inequalities of the country was the lifting of material from

some of the lower horizons and its lodgment on the crests of ridges or the slopes or summits of mountains that lay athwart its course.

So again, it is certain that a considerable part of the peripheral drainage of glaciers takes place through tunnels beneath the ice. It is reasonable to suppose that during the winter season, when the drainage is slack, these tunnels tend to collapse in greater or less degree, under the continued pressure of the ice and the "fattening" of the glacier, so that in the early part of the next melting season the contracted tunnels may be overflooded by glacial waters. To the extent that these tunnels become incompetent the water would become ponded back in the crevasses and moulins by which the surface-water gains access to them. They thus come to have something of the force of water flowing in tubes, and may be presumed to be capable of forcing rounded material to some considerable height, and of carrying ice-imbedded boulders to any point reached by the stream. These tunnels probably undulate with the bottom, and lodgment along them takes place wherever enlargement permits.

Without, therefore, appealing to any upward cross currents within the ice itself, it is possible to explain the transportation of the drift from lower to higher altitudes. I have never seen phenomena of this kind that seemed to call for any other explanation than these. I am not prepared to say that there are no such phenomena. One of the purposes of this article will have been accomplished, if it shall call forth a critical statement of phenomena that require the assumption of internal upward movements of the ice to account for them, and of the criteria which distinguish such phenomena from those that may be referred to upward basal movements such as are common to all streams or to the exceptionally conditioned subglacial streams. That there are upward internal movements in most streams is as much beyond question as the existence of upward basal currents in rivers and glaciers, but they are dependent chiefly upon the velocity of the current and the irregularity of the bottom.

Theoretically, as I understand, a stream moving in a straight course on a perfectly smooth bottom would not develop an upward cross current. Each lower layer would move slower than that above it by reason of basal friction, but they would move on in parallel lines. But if irregularity of bottom be introduced the parallelism is obviously destroyed, and if the velocity be high so that the momentum of the particles becomes great relative to their cohesion, irregular internal movements will result, and these will often be of a rotary nature in vertical planes bringing the basal parts of the fluid to the surface or the reverse. For this reason rapid streams abound in rotary currents, while slow streams do not.

Now it is quite obvious that a stream of water moving at a rate of three or four feet per day, or even fifty or sixty feet per day, would not develop perceptible upward currents, and certainly would not lift the lightest silt from its bottom. I do not think there are any theoretical grounds for believing that internal glacial currents are developed, which flow from base to surface, carrying bottom debris to the top.

One of the most remarkable expressions of the drift phenomena of the Upper Mississippi region consists of belts of boulders stretching for great distances over the face of the country, and disposing themselves in great loops after the fashion of the terminal moraines of the region with which they are intimately connected. Besides this, there are numerous patches of boulders of more or less irregular form and uncertain relations. The whole of these have not been studied in detail, but a sufficient portion of them have received careful examination to justify the drawing of certain conclusions from them. Those which have been most studied lie in Ohio, Indiana, Illinois, Michigan, Wisconsin, Iowa and Dakota. Those of the first three States have been most carefully traced and their constitution is such as to give them the greatest discriminative value. To these our discussion will be limited chiefly.[1]

[1] Parts of these tracts were long since described by Bradley of the Illinois Survey. (Geol. Surv. Ill., Vol. IV. p. 227). Collet of the Indiana Survey (An. Rep. 1875,

Emerging from the dunes at a point north of the Iroquois river in Jasper county, northwestern Indiana, a well characterized belt of surface boulders stretches westward to the State line, just beyond which it curves about to the south and then to the east, and re-enters Indiana a little south of the northwest corner of Benton county. It soon turns abruptly to the south and reaches the Wabash river near the centre of Warren county. The immediate valley of the Wabash is thickly strewn with boulders from the point where the belt reaches it to the vicinity of West Point on the western line of Tippecanoe county. The uplands, however, do not give any clear indication of the continuity of the belt, and the connection is not altogether certain. There is an inner well-marked belt that branches away from this in the central part of Benton county and runs southeasterly into the northwestern quarter of Tippecanoe county, beyond which only scattered boulders occur, which leaves its precise connections also in doubt. But starting from West Point, which is less than a dozen miles from the point where the two belts cease to be traceable with certainty, a well-defined belt, one or two miles wide, runs southeasterly across the southwestern corner of Tippecanoe county and the northeastern quarter of Montgomery county to the vicinity of Darlington, beyond which its connection is again obscure, although boulders occur frequently between this point and the northwestern corner of Brown county, where boulders are very abundant. So also, patches of exceptionally abundant boulders occur in the west central part of Clinton county. These may be entitled to be regarded as a connecting link between the train which enters northwestern Tippecanoe county and that of northwestern Boone county, as scattered boulders of the surface type, but of not very exceptionally frequent occurrence, lie between them. However this may be, a belt of much more than usually frequent surface boulders stretches southeasterly to the vicinity of Indianapolis,

p. 404) and Orton and Hussey of the Ohio Survey (Geol. Surv. Ohio, Vol. III., pp. 412, 414 and 475). The relationship of these tracts to morainic lines and to each other I worked out some years since (Third An. Rep. U. S. G. S. pp. 331, 332, 334) but I owe many details and some important additions to my associate, Mr. Leverett.

and probably connects with a very well-marked belt lying near the south line of the southeast quarter of Marion county and in the northeastern part of Johnson county. There is also a well-defined tract in southeastern Hendricks county, running east and west, without evident connection with the foregoing tracts, though it may be the equivalent of the Darlington belt. There is also a somewhat unusual aggregation in the form of irregular belts in southeastern Johnson county, in the vicinity of Nineveh, and in southern Shelby county. The belt south of Indianapolis is probably to be correlated by scattered boulders only slightly more abundant than those of the adjacent region, but of the surface type, stretching northeasterly to near the center of the west half of Henry county, where a well-marked belt again sets in. From this point the tract runs northeasterly nearly to the north limit of the county, where it turns easterly and runs in the vicinity of the line between Randolph and Wayne counties to near the Ohio line, where it curves to the southeast entering Ohio near the northwest corner of Preble county. In its southeasterly course across that county it is phenomenally developed as has been well shown by the descriptions of Professor Orton. Soon after entering Montgomery county it curves about to a northeasterly course, and crossing the great Miami river, a few miles above Dayton, holds its northeast course across the southeastern part of Miami county, the northwestern part of Champaign county, and thence on to about the center of Logan county, where it curves about and runs in a direction a little east of south to near the southeast corner of Champaign county, beyond which it ceases to be a specially notable phenomenon.

In the region between the Wabash and Kankakee rivers, in northern Indiana, there are numerous tracts of irregular form over which surface boulders in phenomenal abundance are scattered. These are particularly noticeable in southern Jasper county; in the vicinity of Wolcott, Monon and Chalmers in White county; near Star City in Pulaski county; in the southeastern corner of Stark county, and very generally along the great interlobate moraines, lying parallel with the Eel river,

and some others of the Saginaw glacial lobe. These are so associated with the inter-tangled morainic phenomena of that region as not to admit of convenient and brief description in their genetic relationships.

The well-defined tracts have a most significant distribution. The first part described is associated with the terminal moraine that marked the margin of a lobe of ice that moved westward along the axis of the Iroquois basin to a point a few miles beyond the Indiana-Illinois line. The portion that runs southward to the Wabash is associated with the moraine that follows the same course, and runs at right angles over the older moraines of the Lake Michigan lobe. The tract in Tippecanoe and Montgomery counties, that in south Marion county, and that in Henry and Randolph counties, in the eastern part of the state, are associated with the terminal moraines that form a broad loop with the West White river basin lying in its axis. In western Ohio the belt is intimately associated with a moraine that bordered the Miami lobe of the ice sheet, and the south-trending portion in eastern Logan and Champaign counties lies on the western margin of the Scioto lobe.

The relationship of these tracts to terminal moraines is very clear and specific. They constitute marginal phenomena of the ancient ice sheet. Their distribution completely excludes their reference to floating ice, for they not only undulate over the surface utterly negligent of any horizontal distribution, but they are disposed in loops in crossing the basins of the region, and the convexities of these loops are turned down stream. These basins for the most part open out in southerly or westerly directions which makes it improbable that ice-bearing bodies of water occupied them. But if this were not fatal, certainly the fact that the convexities of the boulder belts are turned down stream and cross the centers of the basins is precisely contrary to the distribution they must have assumed if they were due to floating ice in bodies of water occupying the basins. I hold it, therefore, to be beyond rational question that these tracts were deposited as we find them by the margins of the glacial lobes that invaded the region.

If these boulder belts were of the same nature as the average boulders of the till-sheets beneath them, then the simple fact of unusual aggregation might be plausibly referred to the accidents of gathering and deposition. But they are very clearly distinguished from the average boulders of the till by several characteristics.

1. They are superficial. Sometimes they rest completely on the surface, sometimes they are very slightly imbedded, sometimes half buried, sometimes they protrude but a slight portion, and sometimes they are entirely concealed, but lie immediately at the surface. In all cases the aggregation is distinctly superficial. Where they are buried, the burying material is usually of different texture and composition from the subjacent till, and appears to be distinct in origin from it. The superficiality of the tract is very obvious almost everywhere, and is especially so in regions where the subjacent till is of the pebble-clay rather than boulder-clay order, for the comparative absence of boulders below emphasizes the contrast. Throughout most of the region the subjacent till is not of a very bouldery type, so that the distinction is generally a marked one.

2. The boulders of the belts are almost without exception derivatives from the crystalline terranes of Canada. Those of the great tract especially under consideration were derived from the typical Huronian rocks of the region north of Lake Huron, and from granitic and gneissoid rocks referable to the Laurentian series of the same region. These last, however, cannot be sharply distinguished from the granitic rocks derived from other parts of the Laurentian terrane. The Huronian rocks are very easily identified because of the peculiarities of some of the species. Among these the one most conspicuously characterized is a quartz-and-jasper conglomerate. The matrix is usually a whitish quartzite. This is studded with pebbles of typical red jasper and of duller rocks of jasperoid nature, which grade thence into typical quartzite pebbles. With these are mingled crystalline pebbles of other varieties. Another peculiar erratic comes from the "slate conglomerate" of Logan. It consists of

a slaty matrix through which are scattered rather distantly pebbles of granitic, quartzitic and other crystalline rocks. This is one of the forms of the "basal conglomerate" of Irving. Other varieties of this "basal conglomerate" are present. In addition to these very peculiar rocks, a quartzite of a very light greenish semi-translucent hue has a wide distribution along the tract. It is readily distinguishable from the numerous other quartzites of the drift of the interior. Some years since, on returning from my first field examination of a portion of this belt, I sent a typical series of chips from the characteristic erratics to Professor Irving, who had recently returned from the study of the original Huronian region. He returned a suite of chippings that matched them perfectly throughout, all of which were taken *in situ* in the region north of Lake Huron.

Among the boulders of the belt are occasionally found specimens of impure limestone or of limy sandstone that might perhaps be referred doubtfully to some member of the paleozoic series; but on the other hand, might with equal or greater probability perhaps be referred to the similar rocks of the Huronian series. These are quite rare, never forming, so far as my observations go, as much as one per cent. of the series. In the several definite enumerations made to determine the percentage of the doubtful specimens, the result never exceeded a fraction of one per cent. In the most extensive enumeration the result was about one-half of one per cent. Aside from these doubtful specimens there are practically no boulders in the belts that can be referred to any of the paleozoic rocks that intervene in the 500 miles between the parent series north of Lake Huron and the tract over which the boulders are now strewn. Occasionally there may be seen erratics from the paleozoic series at or near the surface, but they are not usually so disposed on the surface as to appear to be true members of the superficial boulder tract. There is, therefore, the amplest ground for the assertion that these boulder tracts are of distant derivation, and that they are essentially uncommingled with derivatives from the intermediate region.

3. The boulders of this series are much more angular than those of the typical till sheets. Some of them, indeed, are rounded, but the rounding is generally of the type which boulders derived by surface degradation and exfoliation present. They rarely have the forms that are distinctively glacial. Quite a large percentage are notably angular, and have neither suffered glacial rounding nor spherical exfoliation. Some few are glacially worn and scratched, but the percentage of these is small.

The tracts therefore present these four salient characteristics: (1) the boulders are derived from distant crystalline terranes (400 to 500 miles) and are essentially uncommingled with rock from the intervening paleozoic terranes; (2) they are essentially superficial, and the associated earthy material has a texture differing from that of the subglacial tills; (3) they are notably angular and free from glacial abrasion, except in minor degree; (4) the tracts are so associated with terminal moraines and so related to the topography of the region, that there is no rational ground for doubt that the boulders were borne to their present places by the glaciers that produced the correlative moraines.

In contrast to these superficial boulder formations, the till sheets below are made up of a very large percentage of glacial clay whose constitution shows that it was produced in part by the grinding down of the paleozoic series. In this are imbedded boulders and pebbles that were derived from the paleozoic series as indicated by their petrological character, and, in many instances, demonstrated by contained fossils. While a small part of the boulders contained in the till are angular or but slightly worn, the larger part are blunted, bruised, scratched and polished by typical glacial action. This obvious grinding of the boulders, taken in connection with the clay product resulting from the grinding, affords a clear demonstration that the deposit was produced at the base of the ice by its pushing, dragging, rolling action.

The two formations, therefore, stand in sharp contrast; the

one indicating the passive transporting action of the ice in bearing from their distant homes north of the lakes the crystalline boulders and dropping them quietly on the surface, the other indicating the active dynamic function of the ice in rubbing, bruising and scoring the material at its base. The one seems to me a clear instance of englacial and superglacial transportation; the other an equally clear example of subglacial push, drag and kneading.

Now if it were the habit of an ice-sheet of this kind to carry material from its bottom to the surface by internal movement, it would seem that the distance of 400 to 500 miles which intervened between the source of the crystallines and the place of their deposit would have furnished ample opportunity for its exercise, and that there would have been commingled with the englacial and superglacial material many derivatives from the intermediate region, and these derivatives should have borne the characteristic markings received by them while at the base of the ice. The very conspicuous absence of such commingling, and the absence or phenomenal rarity of anything that even looks like such a commingling, appears to me to testify in quite unmistakable terms to the distinctness of the methods of transportation. In view of the great territory over which this particular belt is spread, and the greater territory which is embraced in the other tracts not here specially considered, there is left little ground for doubt that this distinctness of englacial from basal transportation was a prevailing fact and not an exceptional one. This is supported by concurrent evidence derived from the territory west of Lake Michigan. This territory unfortunately does not bear erratics that have equally distinct characteristics, but, so far as my observation goes, the phenomena are alike throughout. I am therefore brought to the conclusion that, in the interior at least, there was no habitual lifting of boulders from the base of the ice sheets to the surface, nor any habitual commingling of basal with englacial and superglacial material, except, of course, as it took place by virtue of the falling of the latter through crevasses to the base, and by mechanical intermixture of the two at the edge of the ice.

The amount of englacial till under this view is little more than that which was lodged in the body of the ice in its passage over the knobs and ridges of the hilly and semi-mountainous regions of the north. To this is perhaps to be added occasional derivatives from the more abrupt prominences of the paleozoic region and the superficial dust blown upon the ice from the surrounding land, which was probably the chief source of the silty material intermingled with the superficial boulders. The total amount is thus quite small, though important in its significance

The eskers and kames of the region are made up of derivatives from the basal material as shown by (1) the local origin of the material in large part, (2) the mechanical origin of the sands and silts, (3) the not infrequent glacial markings of the pebbles and boulders, and (4) the disturbed stratification of the beds.[1] If I am correct in respect to the kind and amount of the englacial and superglacial material, it is obvious that eskers and kames, such as are found in the interior, could not be derived from englacial or superglacial sources. The term englacial as here used does not include such materials as may be lodged in the basal stratum of the ice and brought down to the actual bottom by basal melting.

The conclusions drawn from the phenomena of the plains of the interior are not necessarily applicable to more hilly or mountainous regions.

T. C. CHAMBERLIN.

[1] See "Hillocks of Angular Gravel and Disturbed Stratification," Am. Jour. Sci. Vol. XXVII., May 1884, pp. 378–390.

Studies for Students.

DISTINCT GLACIAL EPOCHS, AND THE CRITERIA FOR THEIR RECOGNITION.[1]

I. Introduction.

It has long been evident that writers on glacial geology are not at one concerning some of the important questions which underlie the interpretation of the history of the glacial period. Certain recent publications have served to emphasize the differences between them. There are two questions, at least, concerning which there must be agreement, or at any rate a common understanding, before existing differences can be eliminated or justly evaluated. When the answers to these questions have been agreed upon, or when the positions of the contending parties are clearly understood, it may be found that some of the apparent antagonisms have no better basis than differences in definition. Stated interrogatively, the two questions referred to are these: 1. What constitutes a glacial epoch as distinct from other glacial epochs? and 2. What are the criteria for the recognition of distinct glacial epochs, if such there were?

II. The Idea of a Glacial Epoch.

It is conceivable that, after the development and extension of a continental ice-sheet, it might be wholly wasted away. The maximum extension of such an ice-sheet would mark the culmination of a glacial epoch. If subsequently another ice-sheet of considerable dimensions were accumulated, its development and extension would constitute a second glacial epoch. These successive ice-sheets might be so related to each other in

[1] Read before the American Geological Society at Ottawa, Dec., 1892.

time, in position, and in the sequence of geological events, as to be regarded as separate epochs of the same glacial period.[1] On the other hand they might be so widely separated from each other in time, in position, and in the sequence of geological events, as to make their reference to separate glacial periods more appropriate. In any case their separation would be sufficiently marked to necessitate their reference to separate ice epochs. So far we believe there would be no disagreement.

If, instead of entirely disappearing, the first ice-sheet suffered great reduction of volume and area, and if this reduction were followed by a second great expansion of the ice, might the time of such expansion be regarded as a second glacial epoch of the common glacial period? To this question, too, as thus stated, we apprehend there would be but one answer, and that affirmative.

It seems certain that the edge of the continental ice-sheet was subject to more or less extensive oscillations, as are the ends of glaciers and the edges of ice-sheets to-day. How much of an oscillation is necessary, and under what attendant conditions must it take place, in order that the recession of the ice-edge shall mark an interglacial and its readvance a distinct glacial epoch? When the question takes this specific form, and when inquiry is made concerning the quantitative value of the different elements entering into the problem, we reach the battled ground. It is the battled ground, partly because it is the ground of misunderstanding. It is the ground of misunderstanding, partly because glacialists are not agreed as to the meaning of certain terms in common use by them.

Four elements seem to enter into the idea of an ice epoch as distinct from other ice epochs. These are (1) the distance to which the ice retreated between successive advances; (2) the duration of the retreat, or the time which elapsed between successive ice extensions; (3) the temperature of the region freed from ice during the time between maxima of advance; and (4)

[1] The terms period and epoch are here used in the sense in which they have been used most commonly in the literature of glacial geology in the United States.

the intervention between successive advances, of changes interrupting the continuity of geological processes.

(1.) It would be arbitrary to name any definite distance to which the ice must recede in order to constitute its re-advance a distinct ice epoch. It would be not so much a question of miles as a question of proportions. Considering this point alone, we presume it would be agreed that an ice-sheet should have suffered the loss of a very considerable proportion of its mass, and that it should have dwindled to proportions very much less than those subsequently attained, before its re-advance could properly be called a separate glacial epoch. To be specific, if the North American ice-sheet, after its maximum extension, retreated so far as to free the whole of the United States from ice, we should be inclined to regard a re-advance as marking a distinct ice epoch of the same glacial period, if in such re-advance the ice reached an extension comparable with that of the earlier ice-sheet. Especially should we be inclined to refer the second ice advance to a second glacial epoch, if it, as well as the preceding retreat, were accompanied by favoring phases of some or all the other three elements entering into the notion of a glacial epoch. In this statement we do not overlook the fact that a northerly region—as Labrador or Greenland—might be continuously covered with ice throughout the time of the two glaciations of the more southerly regions. But this is not regarded as a sufficient reason for discarding the notion of duality. Greenland has very likely been experiencing continuous glaciation since a time antedating that of our first glacial deposits. The renewal to-day of glaciation comparable in extent to that of the glacial period would certainly be regarded as a distinct glacial epoch, if not a distinct glacial period, even though Greenland's glaciation may not have been interrupted. Scandinavia and Switzerland have probably not been freed from ice since the glacial period. Their snow and ice fields are probably the direct descendants of the ice fields of the glacial period. An expansion of the existing bodies of ice in these countries to their former dimensions, would constitute a new glacial epoch, if not a new glacial period.

Analogous subdivisions in pre-Pleistocene formations have been frequently recognized.

(2) The application of the time element is hardly susceptible of quantitative statement. We are inclined to think that it would be generally agreed that, with a given amount of recession of the ice, its re-advance would be more properly regarded as a distinct glacial epoch if the interval which had elapsed since the first advance were long. Whether a longer time between the separate advances might reduce the amount of recession necessary in order to constitute the second advance a second epoch, we are not prepared to assert; but we are inclined to think it might.

(3) The third element is perhaps somewhat more tangible than the second. If, during the retreat of the ice, the climate of a region which was twice glaciated became as temperate as that of the present day in the same locality, we should be inclined to regard the preceding and succeeding glaciations as distinct ice epochs, especially if the intervening recession were great and its duration long.

Unfortunately for simplicity and ease of determination, there are difficulties in determining with precision how far the ice retreated between successive maxima of advance, how long the interval during which it remained in retreat, and the extent to which the climate was ameliorated, as compared with that which went before and that which followed.

(4) If changes of any sort which interrupt the continuity of geological processes intervened between successive maxima of advance of the ice, the separation of the later advance from the earlier, as a distinct ice epoch, would be favored. How great the intervening changes should be in order to constitute the re-advance a distinct ice epoch, is a point concerning which there might be difference of opinion. But it is altogether possible that such changes might intervene as alone to give sufficient basis for the separation. Orographic movements, resulting either in continental changes of altitude or attitude are among the events which might come in to separate one ice

epoch from another. Changes of this sort have often furnished the basis for the major and minor divisions of time in other parts of geological history, so that there can be no question as to their adequacy, if they were of sufficient magnitude. We hold that the intervention of orographic or other important geologic changes might reduce to a minimum the amount of recession, the duration of the recession, and the warmth of the intervening climate necessary to constitute the separate ice advances separate ice epochs. The absence of great orographic or other changes in glaciated regions between successive advances of the ice would be no proof that such advances should not be regarded as separate epochs. Divisions of equal importance have often been made without evidence of such changes.

From the foregoing discussion, brief as it is, it will be seen that within certain narrow limits the definition of a glacial epoch, as distinct from other glacial epochs, must be more or less arbitrary. It is less important that an arbitrary definition should be accepted, than that the same meaning should be attached to technical terms in common use among geologists. In the interest of harmony and of a common understanding, and without the violation of any truth of science, we believe it would be well if the conception of a glacial epoch, as framed by those who are our leaders in position and in fact, were made the basis for our usage of the term.

III. The Criteria of Distinct Glacial Epochs.

If there have been differences of opinion concerning the nature of ice epochs, as distinct from each other and from ice periods, there has been a failure to adequately apprehend the nature, the extent, and the meaning of the real criteria on which the final recognition of separate ice epochs, if such there were, must be based.

Such criteria are several in number. They are of unequal value. In some instances a single one of them might be quite sufficient to establish the fact of two ice epochs. In other cases, single criteria which might not be in themselves demonstra-

tive, have great corroborative weight, when found in association with others. In all cases, much discretion much be used in the interpretation of these criteria. They may be enumerated under several specific heads.

(1) *Forest Beds*. Beds of vegetal deposits or old soils are frequently found between layers of glacial drift. This is one of the criteria most commonly cited, because it is of common occurrence and easy of recognition. The advocates of the unity of the glacial period maintain that such beds of organic matter might become interbedded with morainic debris during minor oscillations of the ice's edge. The phenomena of existing glaciers make it evident that forest beds or soils might be enclosed by the deposits of an oscillating ice edge. By repeated oscillations of the ice's edge during the general retreat of the ice, such vegetal beds might become interstratified with glacial drift more or less frequently over all the area once covered by the ice, and from which it has now disappeared. The mere presence of vegetable material between beds of drift is therefore no proof of distinct ice epochs. This does not destroy the value of the vegetal beds as a criterion for the recognition of distinct ice epochs, but it makes caution necessary in its application. It does not follow that, since *some* inter-drift forest-beds do not prove interglacial epochs, *none* do. The question is not how forest-beds might originate, but how existing forest-beds did originate.

Where the plant-remains found in the relations indicated are so well preserved as to make identification of the species possible, we have a means of determining, with some degree of accuracy, the climatic conditions which must have obtained at the place where the plants grew during the time of their life. If these interbedded plant-remains are of such a character as to indicate a temperate climate, we can not suppose that they grew at the immediate edge of the ice, and therefore that they were buried beneath its oscillating margin. To be specific, if the inter-drift plant remains in any given locality of the area once covered by ice are such as to indicate a climate *as warm as the present in the same locality*, the ice must have receded so far to

the northward that its re-advance might, in our judgment, appropriately be regarded as a separate ice epoch.

It has been suggested in opposition that temperate conditions may obtain even up to the edge of the ice, and that interbedded vegetal remains indicating temperate climate do not prove any considerable recession of the ice. The phenomena about existing glaciers have been appealed to in support of this demurrer. But the objection is not well taken. The climatic conditions which obtain about the borders of small, local glaciers, are not a safe guide as to climatic conditions which obtained about the margin of a continental ice-sheet, any more than the climatic conditions which obtain about a small inland lake are a safe criterion as to the climatic conditions about a sea-coast. The general principles of climatology, as well as specific facts concerning plant distribution, seem to us to indicate that the climate about the border of a continental ice-sheet must have been arctic.

It is evident that the greater the distance north of the overlying drift remains of temperate plants are found, the more conclusive becomes the evidence. Plant remains indicating temperate climate at the very margin of the drift sheet which overlies them, would be less conclusive than similar evidences one hundred miles to the northward. It might be difficult to prove in any given instance that the ice which deposited the drift overlying plant remains advanced one hundred miles, or any other specific distance, south of any particular underlying forest bed. If the forest bed were continuous for the whole distance, the case would be clear. It would also be conclusive if the continuity of the drift overlying a forest bed at any point with that of a remote point to the south, could be demonstrated. In spite of these difficulties in its application, the vegetal beds constitute a valuable criterion in making the discriminations under consideration, when they are properly applied. Under proper circumstances the criterion may be conclusive when taken alone, and it may have corroborative significance when not itself conclusive.

The absence of forest beds and of all traces of vegetal deposits whatsoever between beds of drift, is no proof of the absence of

recurrent ice epochs, since the second advance of the ice might have destroyed all trace of the preëxistent soil and its vegetal life. It is always possible, too, that such beds exist, even if they have not been discovered. It would have been anticipated that they would not be abundant, or wide spread. The absence of forest beds is therefore at best no more than negative evidence.

(2) *Remains of Land Animals.* Bones of mammalia or remains of other land animals, occurring in relations similar to those in which forest beds occur, may have a like significance. Their value as a criterion of separate glacial epochs is subject to essentially the same limitations as forest beds.

(3) *Inorganic Products formed during a time of Ice Recession.* The recession of the ice after a maximum of advance would leave a land surface more or less affected with marshes and ponds. In such situations, bog iron ore might accumulate, if conditions were favorable. Such ore beds, buried by the drift of a later ice advance, would have a significance comparable to that of forest beds, except that they would give less definite information as to climate, and would be correspondingly less trustworthy. Should such ore beds be found in such relations as to prove that the underlying and overlying bodies of drift were deposited by ice sheets which extended great distances further south, their significance would be enhanced. From the thickness of the ore beds some inference might be drawn as to the length of time concerned in their accumulation. But because of the variable rate at which bog ore may accumulate, such inference should be used with caution.

Concretions of iron oxide might be formed in the marshes or in ill-drained drift areas where accumulations of greater extent were not made. A subsequent incursion of the ice might incorporate these nodules with its drift, wearing and striating them as other stones, and depositing them as constituent parts of the later drift. Such iron nodules in the later drift would mean a recession and re-advance of the ice with some considerable interval between, although not necessarily an interval sufficiently

warm or long to be regarded as an interglacial epoch.[1] Calcareous concretions, like those of the loess, would possess a like significance, in like relations. While in themselves these inorganic products of a time of ice recession might fail to be conclusive of separate ice epochs, they might have much corroborative significance when associated with other phenomena. An inter-till iron ore bed, associated with a forest bed which indicated a warm climate, would be most significant.

The absence of knowledge of ore beds between sheets of till, and the absence from an upper bed of till of concretions of iron and lime carbonate formed during a recession of the ice, would be no proof that interglacial epochs did not occur. These products were probably formed in relatively few localities. They stood good chance of destruction at the hands of the returning ice, and they may exist, where they have not been discovered, or where their significance has not been understood. Their absence is at best no more than negative evidence.

(4) *Beds of Marine and Lacustrine Origin.* If between beds of glacial drift there be found beds of lacustrine or of marine origin, such beds would indicate a recession of the ice during their time of deposition. Their position would be a minimum measure of ice recession. If such lacustrine beds contain organic remains, they will bear testimony concerning the climatic conditions which existed where they occur, at the time of their deposition. If the fossils in such beds denote a temperate climate, or a climate as mild as that of the present day in the same region, the ice must have receded so far to the northward as, in our judgment, to constitute its re-advance a distinct ice epoch. This line of argument may be even stronger than that drawn from remains of terrestrial life, since the ice would probably affect the temperature of the sea to greater distances than that of the land, and affect it to a greater degree within a given distance. The argument becomes stronger the further north the inter-drift marine and lacustrine deposits occur, since the ice must always

[1]This point concerning iron nodules was suggested to the writer by Mr. W. J. McGee.

have receded to a position still further north. If marine or lacustrine beds lying far north of the later ice limit contain proof of temperate climate, the argument becomes conclusive.

The absence of marine and lacustrine deposits between beds of drift, would be no proof that interglacial epochs did not occur. Lacustrine beds could be made only where there were lakes, and lakes would be the exception rather than the rule. Marine beds in similar positions would rarely be known, except where a definite succession of changes of level has taken place. Both classes of deposits, if once formed, would be subject to destruction by the over-riding ice of a later epoch, if such there were. Neither would be likely to be preserved at all points where formed, and both may exist at many points where their existence is not known. The absence of these beds is at best no more than negative evidence.

(5) *Beds of Subaërial Gravel, Sand and Silt.* Layers of stratified drift between layers of ground moraine, are of common occurrence in many regions. Under ordinary conditions their existence is not regarded as evidence that the underlying and overlying tills are to be referred to separate ice epochs. But it is conceivable that beds of stratified drift may, under the proper circumstances and relations, be strong evidence of separate ice epochs. The last stages of ice work in the glacial period were accompanied, in many regions, by the deposition upon adjacent land surfaces, of extensive bodies of gravel and sand, washed on beyond the ice by waters issuing from it. Except in valleys through which strong currents coursed, such deposits were apparently not carried far beyond the edge of the ice. But as the edge of the ice withdrew to the northward, sand plains may have extended themselves in the same direction, by additions to their ice-ward faces. It is conceivable that the process of subaërial plain building at the edge of a receding phase of ice, might be carried so far under favorable circumstances, as to result in the construction of plains[1] of great extent. In this event, a subsequent ice-advance might overspread such plains in such wise as to bury, without destroying them, though such a course of

events would certainly be exceptional. In order to constitute the inter-stratified gravel and sand evidence of separate ice-epochs, its continuity for great distances between beds of till, and in the direction of ice movement, would need to be demonstrated. In themselves, these beds, under the conditions indicated, would simply be a minimum measure of the amount of ice recession between the deposition of the underlying and overlying bodies of till. It is hardly likely, though possible, that the continuity of inter-bedded gravel and sand could be proved for a sufficient distance north of the southern limit of the less extensive bed of ground moraine, to alone constitute evidence of a recession of ice great enough to make it necessary to refer its re-advance to a new epoch. Beds of silt in like relations, deposited by waters beyond the edge of the ice, would have a like significance so far as the question here under consideration is concerned. Such beds of stratified drift might sometimes have corroborative value when their testimony, taken by itself, is inconclusive. If, for example, their surfaces are marked by forest beds, and especially by forest beds whose plants denote a warm climate, the association becomes most significant.

In view of what has been said, it is evident that the absence of beds of subaërially stratified silt, sand, and gravel, between beds of till can not be brought in evidence against separate ice epochs. It would rarely be true that topographic and hydrographic conditions would make possible the construction of plains of sufficient extent to serve as criteria for the purpose here indicated, and few of those formed would escape such a degree of destruction as to leave them demonstrably continuous. There is also the further possibility that such beds exist, even though their continuity be not known. To prove the continuity of a buried bed of stratified and incoherent drift, even if it existed, would be a most difficult task.

(6) *Differential Weathering.* If, after covering a given region, the ice retreated, the drift which it left in the area which it previously covered would be subject to oxidation, leaching and disintegration. The depth to which this oxidation, leaching

and disintegration would extend, would be dependent upon the length of time during which the drift was exposed, and upon the climate which affected the region during its exposure. The longer the exposure and the warmer the climate, the deeper would the weathering extend. If, subsequently, the ice extended over the same region, it might, in some places, override and bury the old surface without destroying it. The earlier oxidized and leached drift would thus come to be buried by the newer, unoxidized, unleached drift. If, therefore, beneath the newer drift of any given locality there be found a lower drift, the surface of which is oxidized and leached to a considerable depth, the evidence is strong that the lower drift was exposed for a long period of time before the upper drift was deposited upon it. Within certain limits a similar result might be brought about, it is true, if the ice, after having reached a certain maximum stage of advance, were to retreat for a short distance only and there remain for a very long period of time. A subsequent minor advance might bury the oxidized surface of the drift beyond the position of the long ice-halt. Under these conditions, the climate which would have obtained in the area of the drift exposed during the minor retreat would have been cold, and oxidation, leaching, and disintegration would have proceeded slowly. If they reached considerable depths, the time involved must have been very long. If this surface of oxidized and leached and disintegrated drift were found to reach far to the northward beneath the layer of newer and upper drift, it would indicate a great recession of the ice. We maintain that if it were found sufficiently far north of the margin of the overlying drift, and if its depth were sufficiently great, extending well down below any possible accumulation of superglacial till, it might be a positive criterion of so great a recession of the ice, protracted through so great an interval of time, as to constitute its new advance a separate ice epoch.

There is much reason to believe that the soil developed under the influence of a warm climate differs in some respects from one developed from similar material under other conditions. The well-known fact that red and reddish soils are especially

characteristic of low latitudes and warm climates is significant. If therefore a soil developed on the surface of one sheet of drift and buried by another, be found to possess, in addition to unmistakable marks of long exposure, the peculiar marks which seem to be characteristic of soils developed under high temperatures, the argument gains in strength.

This argument from oxidation and weathering has another application. If in a later advance, following a protracted recession, the ice-sheet failed to reach the limit of its earlier advance, there would remain an area of drift deposited by the first ice-sheet, outside the drift deposited by the later. Now if the time interval between these two advances was great, and especially if during this interval the climate was mild, the oxidation and weathering of the older drift surface would be markedly different in degree from that of the newer. If, under these circumstances, the surface of the older sheet were found to be weathered and oxidized and reddened up to the border of the newer drift sheet, and if here there were found to be a sudden change in the character of the surface of the drift so far as depth and degree of oxidization and weathering is concerned, we should have strong evidence that the one sheet of drift was much older than the other. The statement sometimes urged that the drift which was deposited near the edge of the greatest ice advance would be largely made up of the residual materials which occupied the surface invaded by the ice, would not meet the case. For if it be granted that this statement is qualitatively good, we should find the greatest degree of weathering and oxidation at the extreme margin of the drift, and it should be found to be less and less on receding from this margin. There would in this case be no sudden transition from a deeply weathered and oxidized surface, to one which is fresh and unoxidized, along a definite line. We maintain that if the whole of the drift deposits are referable to one epoch, there should be no sudden transition in the surface of the drift from that which is deeply weathered to that which is not, the one surface being separated from the other by a definite and readily traceable line.

It has been urged against the criterion of differential weathering that superglacial material is or may be thoroughly oxidized before its deposition, and that a layer of oxidized drift between layers of till may be no more than superglacial debris deposited during a minor recession of the ice.[1] We believe that this attempt to eliminate the value of this criterion rests partly on an exaggerated idea concerning the amount of superglacial material, but more especially on a failure to apprehend the real meaning of the argument for the validity of the criterion, and upon a failure to note the limitations imposed upon it by its advocates. It is not affirmed that a layer of oxidized drift between beds of unoxidized drift is *per se* proof of two glacial epochs; but it is affirmed that if such layer of weathered drift can be shown to extend far below any possible superglacial till, into the subglacial till below, in such wise as to indicate that it is the result of subaërial exposure in a warm climate subsequent to its deposition and prior to the deposition of the overlying till, it constitutes the best possible evidence of an interglacial epoch, especially when accompanied by the corroborative testimony of other criteria. It is further affirmed that if the second sheet of drift failed to reach the limit of the first, and if the drift which was deposited by the first and never covered by the second ice-sheet, is more thoroughly and more deeply weathered than that deposited by the second, and especially if the two types of drift surface meet along a definite and readily traceable line, the argument becomes, in our judgment, irrefragable. In its application, this criterion would be infallible only in the hands of one who could distinguish between superglacial and superglacially oxidized material on the one hand, and material subaërially weathered after its deposition, on the other.

In circumstances and relations where the weathering of the drift is not in itself conclusive, it might still have corroborative value in association with other lines of evidence.

The absence of an oxidized and disintegrated zone of drift

[1] This point was urged at the reading of the paper at Ottawa, by Prof. C. H. Hitchcock, Mr. Upham, and others.

below a superficial layer which is not oxidized, would be no proof that there were not distinct ice epochs, since the ice of any later epoch, if such there were, might have planed off the surface of the drift left by its predecessor to the depth of the weathering. The preservation of such surfaces after a second ice invasion must be regarded as the exception rather than as the rule. There is always the possibility, too, that an oxidized and weathered zone marking the surface of an older drift sheet exists, where excavations have not opened full sections of drift to view. The absence of weathered zones of drift beneath the surface, or the absence of knowledge of their existence, is therefore at best no more than negative evidence. The absence of greater weathering of the drift outside the limit of the drift supposed to belong to a later epoch, would be positive evidence against the reference of the two sheets of drift concerned to different epochs.

A specific part of the above line of evidence may be separately mentioned. One phase of weathering is the disintegration of boulders, and this is a point which can be readily applied even by those who are not geologists. If the boulders of one region are much more commonly disintegrated than those of another, and if the two regions are separated from each other by a well-marked boundary line, the inference lies close at hand that the boulders in the one case have been much longer exposed to disintegrating agencies than in the other. It is no answer to this argument to say that the materials lying at the very front of the drift deposits contain boulders which were derived from the disintegrated rock over which the ice has passed, and that they were therefore in a less firm state at the outset. In many cases these boulders have come from great distances, and coming from great distances they must have come in a firm and solid state, else they could not have suffered such extensive transportation, except indeed their position was superglacial throughout their whole journey. This argument has equal force when applied to the area covered by the two sheets of drift where two exist. If within the region of drift under investiga-

tion we find a surface layer of greater or less depth, the boulders of which are hard and fresh, and if beneath this we find another layer of drift, the stony material of which is largely disintegrated, at least in its upper parts, we have good evidence that the surface bearing the disintegrated boulders was exposed for a considerable length of time before the deposition of the overlying drift, which carries fresh boulders. Since the disintegration of boulders is only one phase of weathering, the limitations of this argument are identical with those already noted in connection with the general argument from differential weathering.

(7) *Differential Subaërial Erosion.* If the drift deposited by one ice-sheet were to be exposed for a considerable interval of time, and if the ice in its subsequent advance failed to reach the limit of its first invasion, the two areas should show different amounts of subaërial erosion, since the one has been exposed to the action of air and water much longer than the other. The line which marks the limit of the later ice invasion should be the line of more or less sudden transition from an area without, where stream erosion has been greater, to an area within, where stream erosion has been less.

The point here made can not be met by the suggestion that the greater erosion of the outer area was effected by the water issuing from the ice which had retreated to the position now marked by the border of the area of the lesser erosion. So far as we know, such waters would be depositing, not eroding. Furthermore, much of the erosion of the outer area would have such relation to drainage lines that waters issuing from the ice could never have reached the localities where it is shown.

If the outer and older drift be found to have suffered ten times as much stream erosion as the inner and newer, it is fair to assume that it has been exposed something like ten times as long, if the conditions for erosion are equally favorable in the two regions. The argument has especial weight if it can be found that beneath the newer drift the surface of the older is such as to indicate that it was deeply eroded before the newer

was placed upon it. The argument is stronger the farther from the margin of the newer drift such erosion on the surface of the underlying older drift can be proved to have taken place. In other words, if, in addition to the greater surface erosion of the older drift sheet as now exposed outside the limit of the newer drift, we find a notable unconformity between the newer and the older drift, and especially if this unconformity lie far enough north of the margin of the newer drift, the argument becomes conclusive.

When differential erosion and drift unconformities are not in themselves conclusive, they may have great corroborative value in conjunction with differential weathering, forest beds, or other indications of separate ice epochs.

The absence of observable unconformity between sheets of drift would be no proof that there were not distinct and widely separated ice epochs, since the later ice invasion might have so far modified the surface which it transgressed, as to destroy all patent evidences of unconformity. It would have been anticipated that distinct unconformities in the drift would be rare, even if there were distinct ice epochs, for the same reason that weathered zones and forest beds would be rare. But if the drift which lies outside a line supposed to mark the limit of a sheet of drift belonging to a later ice epoch, be not more eroded than that which lies within such line, the absence of greater erosion in the outer drift is positive evidence against the reference of the drift of the two areas to distinct ice epochs, if conditions for erosion in the two areas are equally favorable.

(8) *Valleys Excavated Between Successive Depositions of Drift.* A closely related, but not identical, point may be found in the extent of the valley excavations which can be proved to have taken place between the deposition of the earlier and later drift. We do not refer to valleys excavated in the drift especially, but to those excavated in other formations as well. If it can be shown, for example, that after the deposition of an earlier drift sheet, and before the deposition of a later, valleys were excavated which extended not merely into the drift itself, but far

beneath the drift into the underlying rock, these valleys would be conclusive evidence of a long interval between the deposition of the two bodies of drift. The argument is of especial force when such excavations in the rock beneath the drift can be shown to have taken place at great distances within the margin of the newer drift. For valleys in such situations imply that the ice had receded at least as far to the north as they lie, during the interval between the two drift depositions, and may be so situated as to show that the ice had wholly left the drainage basin where they occur.

The absence of evidences of deep valley excavations in any given region during a supposed interglacial epoch, is no proof that such interval did not exist. The conditions may not have been everywhere favorable for erosion within the limits of any narrowly circumscribed area, and the absence of interglacial valleys would be only negative evidence against an interglacial epoch. The absence of such evidence everywhere would bear against the existence of an interglacial epoch of much duration in such wise as to be more than negative evidence.

(9) *Different Directions of Movement.* If, after its maximum advance, the ice suffered merely a minor recession and then remained stationary, or nearly so, for a time, the general direction of its movement in a subsequent advance would probably be essentially the same as in the earlier. But if, after its maximum advance, the ice receded to a great distance, and especially if it entirely disappeared, a subsequent ice-sheet might have a very different direction of movement, since its center of accumulation and dispersion might be very different. It is conceivable that this center might shift during the history of a single ice-sheet. In this case there should be a gradual change in the direction of ice movement, not an abrupt one. If, therefore, there be found one sheet of drift made by an ice movement in one direction, overlaid by another sheet of drift deposited by ice moving in a very different direction, with an abrupt transition between them, such drift sheets would be presumptive evidence of distinct ice epochs. An exception would need to

be made in the case of drift sheets along the margins of confluent or proximate ice lobes. In such cases, if the one lobe temporarily secured the advantage of the other, drift beds formed by movements from opposite directions might be found in vertical succession, without being evidence of separate ice epochs.

It is no part of the purpose of this essay to point out the difficulties which might arise in the application of this criterion of diverse directions of ice movements. It is possible that gradual changes in the direction of movement might leave records which would seem to indicate abrupt changes instead. This possibility makes care necessary in the application of the criterion, but does not destroy its value. When not itself conclusive, this criterion may be so associated with differential weathering, differential erosion, forest beds, etc., that their combined testimony makes but one conclusion possible.

The absence of evidence of radically diverse directions of movement during the time of deposition of the various sheets of drift, would be no proof that there were not distinct epochs. In the first place, the movements of different epochs might be harmonious—a condition of things more probable than any other if the more common views of the causes of glaciation be correct. In the second place, if the movements were diverse, the deposits might still be so similar that their differentiation, when the one is buried, might not be easily made. In the third place, the later ice might have so far incorporated the older drift material with that which belonged more properly to it, as to have destroyed all definition between them.

(10) *The Superposition of Beds of Till of Different Physical Constitution.* After the retreat of an ice-sheet, the surface of the country thus discovered would be largely mantled with drift. This drift would serve to protect the underlying rock from disintegration. But where there was little or no drift, the rock surface would be subject to all the disrupting agencies which affect surface rocks. The same would be true of all rock surfaces bared by subaërial erosion after the disappearance of the ice.

Under these conditions, if a second sheet of ice invaded the region in question after it had been long exposed, it would find a surface prepared to yield large bowlders. The result would be the deposition of a new sheet of drift containing bowlders much larger than those which would have been proper to an ice-sheet overspreading a surface but recently abandoned. If, therefore, in the upper of two layers of subglacial till, bowlders of great size predominate, as compared with those of a lower homologous layer, they may be indicative of a great interval of time between the deposition of the upper and lower beds of drift. If the home of these bowlders be far north of the limit of the lesser sheet of drift, the distance, as well as the duration, of the ice retreat must have been great, and the reference of the two beds of till to distinct ice epochs would be favored. The case might be so strong as to make no other interpretation possible. Where in itself inconclusive, this criterion would have corroborative significance. In its application, the discrimination of subglacial and superglacial till would be imperative.

The absence of physical dissimilarity between superposed layers of subglacial till would not be proof of the absence of separate glacial epochs. The phenomena constituting the criterion could hardly be expected to be of common occurrence. They would never be obtrusive, and may easily have escaped attention where they exist.[1]

(11) *Varying Altitudes and Attitudes of the Land.* Another line of argument has to do with the altitude and attitude of the land during the deposition of various members of the drift complex. If during the deposition of one part of the drift that part of the continent covered by the outer part of the ice was low, the drainage from it would be sluggish. If the deposits of this drainage persist to the present time, we may find in their character evidence of the nature of the drainage, and therefore of the attitude of the land. If at a later time of drift deposition the glacial drainage in the same region was more vigorous,

[1] The 10th criterion, in the order here named, was suggested by Mr. McGee in the discussion which followed the reading of the paper at Ottawa.

the deposits made by the glacial streams would be correspondingly coarser. In these deposits, if they persist to the present day, we should find conclusive evidence of the swiftness of the streams. If it can be shown that during the deposition of one sheet of drift drainage was sluggish, and that during the deposition of a later body of drift the drainage was vigorous, these facts are evidence of an interval between the two times of drift deposition, sufficiently long to accomplish the corresponding changes in elevation or attitude. Since such changes of altitude and attitude are generally believed to have been accomplished slowly, the interval must be believed to have been of considerable duration.

It is true that continental altitudes and attitudes might change during a single epoch of glaciation. If the change thus brought about resulted in increased slope, the more sluggish drainage of the earlier part of the epoch would be gradually transformed into the more vigorous drainage of the later part. In this case, if the evidence of both the earlier sluggish drainage and of the later vigorous drainage remain, there should also remain the evidence of the intermediate stages. If the deposits representing the intermediate condition of drainage do not exist, while those representing both extremes do, there would be the best of reason for believing that the intermediate phases of drainage did not exist during a glacial epoch, but during an interglacial epoch, when streams were not handling glacial debris, and when they were eroding rather than depositing. The deposits of the slow and of the swift drainage might occur in such relations as to prove, beyond peradventure, that intermediate stages of *glacial* drainage never existed.

If the sluggish drainage accompanied the maximum ice invasion, while the vigorous accompanied a lesser, the evidence of the swift streams might be found far north of the southern limit of the earlier drift. The farther north of the outer border of the older drift the gravel representing the vigorous drainage of the later and minor ice-sheet occurs, the further the ice must have retreated before the change from the one type of drainage

to the other was effected. On the other hand, the farther north of the limit of the later ice advance the sluggish drainage accompanying the earlier ice-sheet may be traced, the farther must the ice have receded before the changes resulting in vigorous drainage occurred. Under certain relations, the retreat of the ice might be shown to have been great enough, before the orographic movements which altered the nature of the drainage, to constitute in our judgment, a re-advance a distinct ice epoch. If for example throughout the course of a long river whose basin was largely covered with ice, there be evidence that sluggish drainage obtained during the maximum ice advance, and during all stages of the ice retreat until the basin was free from ice, and if there be evidence of a vigorous glacial drainage in the same valley at a later time, with no gradations between the two types, we have proof positive of at least a great recession, and of a considerable elevation of the land after the ice had receded beyond the limits of the drainage basin and before it again reached it in its re-advance. We hold that these phases of glacial drainage deposits may be so related to each other, to the valleys in which they occur, and to more or less distinct bodies of glacier drift, as to prove so great a recession of ice between the diverse phases of drainage deposition, as to constitute the second advance a distinct ice epoch.

The absence of evidence that the land stood at different elevations during different parts of the period of drift deposition, does not in any way militate against the theory of recurrent and distinct ice epochs. A constant attitude of the land is the thing to be assumed, until positive evidence to the contrary is adduced.

(12) *Vigor and Sluggishness of Ice Action.* If it can be shown that during one epoch of glaciation, we will say the epoch of maximum ice extension, the ice action was relatively sluggish, while during a later and minor advance its action was vigorous, the difference of action might be regarded as presumptive evidence of distinct ice epochs. Evidence of the two phases of ice action here referred to are difficult of definition, but they have been

independently noted by more than one glacialist. It is true that a forward oscillation of the ice edge might be more forceful than an earlier forward movement which might have reached a greater extension. In itself, therefore, this line of evidence can not be regarded as possessing great value.

It has been indicated that under certain circumstances, and in certain relations, some of the foregoing criteria, taken singly, may be conclusive of glaciations so distinct from each other, as to make their reference to separate epochs proper. But where the facts and relations which constitute one of the criteria are found, the facts and relations constituting one or more of the others are likely to be found as well. Where two of the foregoing criteria are found to be coexistent, their joint force is greater than that of either one. If neither one be absolutely conclusive, the two may still be, since the one may exactly meet the deficiency of the other. If three or more concurrent lines of evidence exist in any locality, the case is still further strengthened. We maintain that several of the foregoing criteria may be so related to each other and to the formations concerned, as not only to make the recognition of separate ice epochs proper, but to make the failure of such recognition altogether unscientific. Even when a single line of evidence, or when double, or triple, or quadruple lines of evidence are not absolutely conclusive in ruling out every conceivable technical escape from the conclusion that there were separate ice epochs, their cumulative and corroborative force may still be such as to carry conviction scarcely less positive than that which mathematical demonstration would afford. In the nature of the case not all of these various lines of evidence could be expected to be found in any one locality, or perhaps in any one limited geographic area, but where one occurs, some or all of the others are liable to be found under favoring circumstance. The number of criteria, and the great extent of area where they may hope for application, afford great possibilities.

From the foregoing discussion, it will be readily seen that the nature of the criteria and the limitations imposed upon their

application by the difficulty of proving stratigraphic continuity in such a formation as the drift, necessitate the greatest care in their use, and reduce the value of hasty and inexpert conclusions to a minimum.

IV. Areas Where the Criteria find Readiest Application.

The foregoing criteria find their readiest application in regions where a later sheet of drift, suspected of belonging to a later ice epoch, failed to reach the border of an earlier sheet of drift, suspected of belonging to an earlier ice epoch. The 1st, 2d, 3d, 4th, 5th and 10th as enumerated above, find their application wholly within the area affected by the drift of the separate epochs, if such there were. While within this general area they may be looked for at any point, they are likely to be of rare occurrence, except along a somewhat narrow belt, say 50 to 100 miles, adjacent to the border of the lesser ice advance. The conditions for their occurrence and detection are greatly favored if the lesser drift sheet be the later. The 6th, 7th, 9th and 12th criteria might hope for application within the same belt, but especially along a narrow zone on either side of the margin of the later drift sheet. It is along this zone that the types of surface are thrown into sharpest contrast, both as to material and topography. The 8th and 11th criteria have still wider limits of application, both within and without the border of the lesser ice advance.

Rollin D. Salisbury.

EDITORIALS.

It is the chief function of the national, state and provincial geological surveys to bring forth the great concrete facts relative to the structure and resources of their several fields. Within their special domains they also do an important work in the correlation of structures and formations, in the systematic aggregation of the facts, in the organizing of results, and in the development of the fundamental principles of geological science. To some extent they are permitted to do this beyond their own fields, but in the main the boundaries of these fields are the limits of their coördinations. They therefore leave a great function to be performed by some other agency in the coördination of interstate, international, and intercontinental factors. They are also restrained by their relationships to a somewhat too narrowly utilitarian public from devoting much direct attention to the solution of the deeper and broader problems that constitute the soul of science, though their contributions bear upon these in the most radical and important way. In the primary work of systematic observation, and the development of the immediate conclusions that spring therefrom, these surveys surpass all other agencies in the value of their contributions to the growth of the science, but in the secondary and ulterior work of correlation, in the synthetic aggregation and organization of results, and in the analytical and philosophical treatment of the whole, they need to be supplemented by agencies whose facilities and limitations lie in other lines, agencies whose relations and dependencies are complementary in nature. This secondary and ulterior work, in some degree, has been done by individual master students of systematic and philosophical geology, but to a very great extent it has not been done at all. It is a function which properly falls to universities, if the universities can only rise to

meet it; for it is the function of universities, in the larger modern view, not only to rehearse science, nor merely even to educate young geologists, important as that is, but to develop science for science's own sake, and for its own inherent and permanent utilities as distinguished from its immediate applicabilities. To fulfill this function they must not only realize and appreciate it, but they must be equipped for field and experimental work, as well as library and laboratory study. Ideal correlations and academic systematizing are as apt to be hindrances as helps to the progress of science. While a few of the great universities of this country and Europe have made notable advances in these directions, the universities are, on the whole, far behind the great surveys in the performance of the work which properly falls to them. This is due not so much to a lack of appreciation of the function as to the lack of facilities.

With the development of this higher function of the universities there goes a coördinate function for a university journal of geology, a journal whose special efforts shall be devoted to promoting the growth of systematic, philosophical, and fundamental geology, and to the education of professional geologists. No part of the wide domain can wisely be neglected by any journal, but there seems to be an open field for a periodical which specially invites the discussion of systematic and fundamental themes, and of international and intercontinental relations, and which in particular seeks to promote the study of geographic and continental evolution, orographic movements, volcanic coördinations and consanguinities, biological developments and migrations, climatic changes, and similar questions of wide and fundamental interest. This field is not likely to be successfully cultivated except by a systematic endeavor, pursued through a period of years, to bring together the latest and best summations of the results attained in the several national fields in a common medium, where they can be compared and discussed, and where tentative correlations will suggest themselves, out of which, in turn, working hypotheses will naturally spring, leading on to such direct investigations as the nature of each

question invites. It would be presumptuous to assume that the Journal of Geology can cultivate with more than very partial success this field, but it especially invites contributions of this class.

Another phase of geology which is thought to stand in much need of active cultivation is found in the clear and sharp analysis of its processes, the exhaustive classification of its phenomena, especially on genetic bases, the development of criteria of discrimination, the more complete evolution and formulation of its principles and the development of its working methods. The recent opening of new fields of research and the rapid progress of several new and important departments of the science give peculiar emphasis to this need. The rising generation of geologists, the hope of the science, should be schooled in these latest and most critical aspects of the science. A department of the Journal, entitled "Studies for Students," has been opened for the special cultivation of this field and for its adaptation to advanced students and progressive teachers of geology. Mere elementary presentations of processes and principles are not desired, but searching and critical expositions are solicited suited to the needs of young geologists who seek the highest professional equipment, and to progressive teachers who desire the fullest practicable command of the newest developments of the subject. These contributions may not be without their value to those who have already borne a considerable part of the heat and burden of life's professional day.

It is our desire to open the pages of the Journal as broadly as a due regard for merit will permit, and to free it as much as possible from local and institutional aspects. It will have the very important advantage of being published under the auspices and guarantee of the University of Chicago, and will be free from the usual financial embarrassments attending the publication of a scientific magazine. This necessarily imposes upon the local editors the immediate responsibility for its editorship. Beyond this, it is hoped that its institutional relationship will disappear entirely in an earnest effort to promote the widest

interests of the science. As an earnest of this wider effort several eminent geologists, representing some of the leading universities of this country, and some of the great geological organizations of Europe, have kindly consented to act as associate editors. T. C. C.

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Upon invitation of the World's Congress Auxiliary of the World's Columbian Exposition committees were appointed by the several sections of the American Association for the Advancement of Science at its Rochester meeting to coöperate with it in completing the organization of scientific congresses to be held at Chicago in connection with the forthcoming World's Fair. The committee appointed by the geological and geographical section consisted of Thomas C. Chamberlin, John C. Branner, Grove K. Gilbert, W. J. McGee, Rollin D. Salisbury, Eugene A. Smith, Charles D. Walcott, J. F. Whiteaves, Geo. H. Williams, H. S. Williams and N. H. Winchell.

It has been arranged that this committee should undertake the work of preparing the scientific program for the Geological Congress. The committee have prepared a provisional schedule of topics, which they have submitted to the Advisory Council for revision. It has seemed to the committee that all contributions should be such as to have an international interest. Preferably, they should be subjects that can only be treated most advantageously in such a congress, especially those that involve the bringing together of data from different lands for comparison. The committee suggest the organization of the subjects under the following general classes :

First. Such as shall show the present state of geological progress. It is believed that this can best be done by an exhibition of geological maps which shall show the latest and best results of official and other surveys. As such maps will be prepared, it is hoped, for the World's Fair, duplicates can be made at a slight expense for the use of the Congress. It is hoped that each country that has made any notable progress in map-

ping its geological formations will furnish for the Congress at least a general geological map, if not also special or analytical maps.

SECOND. Such subjects as bear upon continental growth and intercontinental relations. It is proposed to make this a leading line of discussion during the Congress, in the belief that there is no subject more appropriate, and that there is none which better represents the present efforts of geologists or commands a more general interest. It is hoped that analytical maps will be prepared by the geologists of the several countries representing the stages of growth of these regions in each of the great eras from the Archean to the Pleistocene, and that such analytical maps may constitute a leading feature of the several presentations. Among the subjects upon which contributions are specially invited are the following: The correlation of continental and intercontinental orographic movements and geographic accretions by sedimentation; The coördination of periods of vulcanism in the different countries; The coördination of climatic states and changes; The correlation of faunal and floral variations and migrations. It is hoped that one session may be devoted to such coördination papers bearing upon each of the great subdivisions: viz., Archean, Paleozoic, Mesozoic, Cenozoic, and Pleistocene.

THIRD. Papers on Paleontological and Archeological Geology of international scope.

FOURTH. Contributions to Physical, Structural and Petrological Geology having international or general bearings.

FIFTH. Contributions to Economic Geology having general bearings.

SIXTH. Miscellaneous papers of especial and general interest.

The foregoing groups are intended to embrace and coördinate the list of special themes announced in the circular issued by the local committee some months since, except such as may be best suited to popular presentation, for which special provision is to be made.

It will be determined later, when the number and nature of the papers are ascertained, whether all will be arranged so as to

form a continuous program, or whether sub-sections will be formed and two or more sessions held simultaneously.

It is the desire of the World's Congress Auxiliary that a few addresses of a popular nature shall be given, with a view to stimulating an interest in the development of the science on the part of the public. T. C. C.

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EXTRA copies of the articles appearing under the head of Studies for Students will be printed and kept on sale for the use of teachers and advanced classes. The prices will be fixed as low as practicable, and a standing list published in the advertising columns of the JOURNAL.

Reviews.

On the Glacial Succession in Europe. By Prof. JAMES GEIKIE. Transactions of the Royal Society of Edinburgh, Vol. XXXVII., Part I. (No. 9), 1892, pp. 127–149 (with a map).

IN this timely essay Prof. Geikie reaches the following conclusions:

1. The record of the first glacial epoch is found in the Weyborn Crag of Britain, and the ground moraine beneath the "Lower Dilu vium" of the continent. During this epoch, the direction of the ice movement in southern Sweden was from the south-east to the northwest. This first glacial epoch of which direct evidence is adduced was followed by an interglacial interval, during which the forest-bed of Cromer, the breccia of Hötting, the lignites of Leffe and Pianico, and certain beds in central France were deposited. During this interglacial epoch, the climate is believed to have been very mild.

2. There followed a second epoch of glaciation, when the ice sheet of Britain became confluent with that of the continent. This was the epoch during which the ice sheet reached its southernmost extension. Its depositions are found in the lower boulder clays of Britain, the lower diluvium of Scandinavia and north Germany (in part), the lower glacial deposits of south Germany and central Russia, the ground moraines and high level gravel terraces of Alpine lands, and the terminal moraines of the outer zone. During this second glacial epoch, Alpine glaciers are believed to have attained their greatest development. This epoch of extreme glaciation was followed by an interglacial interval, during which Britain is believed to have been joined to the continent. During this interval, the climate became temperate. In Russia (near Moscow) there seems to be evidence that it was milder and more humid than that of the same region at the present day. Toward the close of the mild epoch, submergence seems to have been accompanied by an increasing degree of cold, which finally ended in another glacial epoch.

3. The subsidence which marked the close of the second interglacial interval, marked likewise the inauguration of the third glacial

epoch. Its work is represented in Britain by the upper boulder clay, in Scandinavia and Germany by the lower diluvium (in part), in central Russia by the upper glacial series, in Alpine lands by ground moraines and gravel terraces. The ice sheets of Scandinavia and Britain were again confluent, but did not extend quite so far south as during the second glacial epoch. This third glacial epoch is believed to have been followed by another interglacial interval, during which fresh water alluvia, lignite and peat accumulations were made. These are represented by the interglacial beds of north Germany, and by some of the so-called postglacial alluvia of Britain. There were also marine deposits on the coasts of Britain and on the borders of the Baltic. During this interglacial interval, Britain is believed to have been continental. The climate was temperate, but in the course of time became more severe. This increasing severity seems to have been accompanied by submergence, which amounted to something like 100 ft. below the present sea-level on the coasts of Scotland. The Baltic provinces of Germany were also invaded by the waters of the North Sea.

4. There followed a fourth period of glaciation, during which the major part of the Scottish Highland was covered by an ice sheet. Local ice sheets existed in the southern uplands of Scotland and in mountain districts in other parts of Britain, and the great valley glaciers sometimes coalesced on the low lands. Icebergs floated out at the mouths of some of the highland sea-lochs. In some places, terminal moraines were deposited upon marine beds which were then in process of formation. These beds are now 100 ft. above the sea level. At this time Scandinavia was covered by a great ice sheet, which yielded icebergs to the sea along the whole west coast of Norway. The ground moraines and terminal moraines of the mountain regions of Britain represent the deposits of this ice epoch. The upper diluvium of Scandinavia, Finland, and north Germany represent the work of the contemporaneous, but not confluent, ice sheet of the continent. In the Alps, terminal moraines in the large longitudinal valleys were made at the same time.

This fourth glacial epoch was followed by a fourth interglacial interval, during which fresh water alluvial deposits were made, and also the "lower buried forest and peat" of Britain and north-western Europe. At this time, Scotland seems to have stood 45 to 50 feet lower than now, and Carse clays and raised beaches represent the work of the sea. During this interglacial interval, Britain is

believed to have become again continental, while the climate became so far ameliorated as to allow the growth of great forests. Subsequently the insulation of Britain was effected, and this was followed by a climate which was probably colder than the present.

5. The severity of the climate which marked the close of the fourth interglacial interval was such as to bring about local glaciation in some of the mountain valleys of Britain. Here and there the glaciers projected their moraines so far down the mountains that they rest on what is now the 45 to 50 feet beach. In the Alps, this fifth epoch of glaciation is represented by the so-called postglacial moraines in the upper valleys. This is believed to have been the last appearance of glaciers in Britain. The dissolution of these glaciers was again followed by an emergence of the island, and by more genial climatic conditions.

In support of his conclusions, Prof. Geikie cites some striking facts which are not so widely known as they should be. For example, Swedish geologists have found evidences that there was an ice sheet antedating that which deposited the "lower diluvium," and that during this earlier glaciation the direction of ice movement in southern Sweden was from the south-east to the north-west. The ground moraine deposited by this ice sheet is overlain by the "lower diluvium" which was produced by an ice movement from the north north-east to the south south-west, or nearly at right angles to the first. Again, near Moscow, there exist interglacial beds whose plant remains indicate a climate milder and more humid than that of the present time. These interglacial beds, it will be observed, occur in the region of the "lower diluvium" quite beyond the margin of the ice which produced the "upper diluvium" of Germany and Scandinavia. During this interglacial interval, Prof. Geikie maintains that no part of Russia could have been covered with ice. If, then, within the limits of the area covered by the "lower diluvium," and not by the "upper," distinct beds of glacial drift are separated by such beds as those cited, there can be no question but that such separation marks two distinct glacial epochs. If there was an earlier glaciation when the movement of the ice in Sweden was at right angles to that during which the lower part of the "lower diluvium" was produced, this also would seem to be good evidence of three ice epochs prior to the "upper diluvium." The epoch of the "upper diluvium" would then constitute the fourth glacial epoch, and this is the interpretation of Prof. Geikie.

Outside the area of the European continental ice sheet, facts are adduced in striking confirmation of the multiple ice epoch theory. These facts are found in Switzerland, where evidences of multiple glaciation have been recognized, and in the Pyrenees where evidences of three separate ice epochs have been found. In France, evidences of an inter-glacial interval have been found in the region of the Puy de Dôme of such duration as to allow the excavation of valleys to a depth of 900 feet. The length of time which would be required for such stupendous erosion must certainly be regarded as sufficient to allow the preceding and succeeding glaciations to be considered as belonging to two distinct epochs.

Another point of great significance and interest which Prof. Geikie's essay brings out, is the correlation in Britain between epochs of glaciation and epochs of subsidence on the one hand, and between interglacial intervals and epochs of elevation on the other. If Prof. Geikie's interpretation be well founded, and so far as we are able to judge from the facts presented this is the case, his conclusions would seem to be fatal to the hypothesis that glacial climate was produced by northern elevation.

The map which Prof. Geikie gives, showing the limit of ice advance during the fourth glacial epoch, seems to us open to criticism. On the ground of personal observation, the writer believes that the ice sheet of the glacial epoch here represented did not extend notably, if at all, beyond the Baltic Ridge.[1]

Prof. Geikie is an advocate of Dr. Croll's astronomical theory of glacial climate, and thinks that even five is not the full number of glacial epochs belonging to the Pleistocene period. He believes there may have been a series of glacial epochs increasing in severity to a maximum represented by what is now designated as the second glacial epoch. This maximum was followed by a series of epochs of diminishing severity, represented by what he designates the third, fourth and fifth epochs. The essay is a timely contribution to glacial geology. ROLLIN D. SALISBURY.

[1] See *American Journal of Science*, May, 1887. In a recent letter, Prof. Geikie indicates that he is convinced, from subsequent personal observation, that his map is erroneous so far as the limit of the ice of this epoch is concerned. The mapping given was based on the opinion of others.

Analytical Abstracts of Current Literature.[1]

The Sub-Glacial Origin of Certain Eskers. By William Morris Davis, Harvard University. (Proceedings of the Boston Society of Natural History, Vol. XXV., May 18, 1892).

A critical discussion of the conditions under which it is conceived certain eskers and sand plateaus (plains) were formed. The Auburndale district, ten miles east of Boston, presents three classes of modified drift deposits;—sand plateaus, eskers, and kames. These deposits are well exposed.

The sand plateaus have the characteristics of delta deposits of glacial streams,—even surfaces, well-bedded sands and gravels, the beds sloping outward from the "head" at an angle of 12° to 20°, and in close agreement with the slope of the plateau front, a lobate margin, deposits distinctly coarser at the head than near the front, and a series of nearly horizontal roughly cross-bedded gravels overlying the sloping beds.

The eskers are essentially of the same material as that of the plateau, often so poorly stratified as to render differentiation of the beds difficult. The interstices between the pebbles are often unfilled, although there is abundance of fine material in adjoining layers. This "open work" is taken to indicate rapid deposition, and seems to preclude the supposition that the gravels have settled down from a superglacial position, or been traversed by currents of any volume. In several instances the eskers can be followed to direct union with sand plateaus. Towards its lower end the esker frequently "gives out branches" and "the adjacent lowland surface becomes more or less encumbered with sand mounds or kames," indicating a decayed margin of the ice.

Prof. Davis' conclusions are:

"1. The eskers and sand plateaus of Auburndale and Newtonville were formed by running water just inside and outside of the ice margin in the closing stage of the last glacial epoch.

"2. The ice-sheet was a stagnant, decaying mass at the time of their formation, as is shown by the ragged outline of its margin.

[1] Abstracts in this number are prepared by Henry B. Kummel, Chas. E. Peet, J. A. Bownocker.

"3. Eskers and sand plateaus are genetically connected; the term, feeding-esker, is fully warranted by the relation of the two in position, structure, and composition.

"4. The sand plateaus were made rapidly; this is proved by the absence of disordered beds at their heads, where space would have been opened by the backward melting of the ice had the forward growth of the plateau been slow. The eskers were also made rapidly, as is shown by their 'open-work gravels.'

"5. The diversion of the feeding streams to other outlets left the plateaus and the eskers without further energetic action as the ice melted away from them.

"6. The present form and structure of the eskers are more accordant with the supposition of a subglacial origin than of a superglacial origin; but it is not intended to imply that other eskers of more irregular form and different structure could not have been deposited in superglacial channels."

H. B. K.

Studies in Structural Geology. By BAILEY WILLIS, U. S. Geol. Surv. (Transactions of the American Institute of Mining Engineers, June, 1892).

The paper aims "to present some of the results of observation of the geologists of the Appalachian division during the past three years on the subject of structural geology in the Appalachian province." The structural features are all of one type but of different phases, comprised in four great districts. 1) the district of close folding, 2) a district whose chief structural characteristic is cleavage, 3) a district of open folding, 4) a district of faulting and folding. The answer to the questions, Why did the strata bend in the district of open folding, and why did they break in the district of faulting, is that the thrust affected them according to their rigidity under their respective conditions of superincumbent load. "We know that load up to a certain point restrains fracture in material under thrust." In the district of open folding the Devonian limestone is the most rigid of the strata and "the one which would most effectively transmit the compressing thrust and would control the resulting structure." In the district of open folding this limestone was prevented from breaking and faulting by a load of superincumbent strata exerting a pressure of 10,000 to 23,000 pounds per square inch, while in the faulted district a load of 5,000 to 10,000 pounds per square inch permitted the strata to break and fault.

The answer to the question, Why did the compression affect this zone, is given. "It becomes apparent on study of sections that where compression raised a great arch there previously existed a bend from a nearly horizontal to a descending position in the principal stratum transmitting the thrust. Greater anticlines and synclines originated in upward and downward convexity of initial dips, due to unequal deposits of sediments which depress

underlying strata in proportion to their weight. Such folds may be called original." The Pottsville, Mahanoy, Shamokin and Wyoming coal basins of Pennsylvania belong to this class.

Experiments have recently been carried on in the office of the United States Geological Survey reproducing the different forms of folding. The experiments differed from other experiments in that 1) the materials used to simulate the stratified rocks varied in consistency from brittle to plastic, according to the depth at which deformation is supposed to take place; 2) the compression was exerted under a movable load representing the weight of superincumbent strata; 3) the strata rested on a yielding base to simulate the condition of support of any arc of the earth's crust. The following are the conclusions from the experiments:

1. "When a thrust tangentially affects a stratified mass, it is transmitted in the direction of the strata, and by each stratum according to its inflexibility. At any bend the force is resolved into components, one radial, the other tangential to the dip beyond the bend; the radial component, if directed downward, tends to depress the stratum and displace its support.

2. "A thrust so resolved can only raise an anticline or arch which is strong enough to sustain the load lifted by its development; such an arch may be called competent; and since strength is a function of the proportions of a structure, it follows that, for a given stratum, the size of a competent anticline will vary inversely as the load; or for a given load the size will vary as the thickness of the effective stratum.

3. "The superincumbent load borne by a competent anticline is transferred to the supports of the arch at the points of inflection of the limbs.

4. "When a competent arch is raised by thrust from one side, the load transferred may so depress the resulting syncline further from the force that an initial dip will be produced in otherwise undisturbed strata; this dip will rise to a bend from which a new anticline may be developed. This anticline is a result of the first, and may be called 'subsequent' in distinction to original folds. Since subsequent folds are simply competent structures, their size will be determined by conditions of thickness and load, and for like conditions they should be equal; and they must, in consequence of conditions of development, be parallel to the original fold and to each other. An example of an original fold with its subsequent anticlines is the Nittany arch and the group of parallel anticlines which lie southeast of it, extending northeast from the Broad Top basin." C. E. P.

The Catskill Delta in the Post-Glacial Hudson Estuary. By WILLIAM MORRIS DAVIS. (From the Proceedings of the Boston Society of Natural History, Vol. XXV., 1891).

The post-Tertiary trenches of the Hudson and its tributaries are in the main filled with clay beds, which, covered by a thin deposit of sand, rise in

terraces 130, 150, or even 180 feet above tide-water. These clays are the result of a late glacial or postglacial submergence of the valley, but their upper surface does not indicate the amount of their submergence, as they are bottom deposits. Delta deposits made by the tributary streams, where they entered the Hudson estuary, would indicate the amount of submergence.

Such deposits are found on the Catskill a mile north of Cairo, and eroded remnants are traceable for three or four miles down stream. The surface is characterized by great numbers of water-worn stones up to fifteen or eighteen inches in diameter. The lobate margin, where present, is poorly defined. These deposits range from 290 feet (aneroid) above tide, up river, to 270 feet further down. One-tenth of a cubic mile of material seems to have been washed into the Catskill trench at the point of this delta between the time of the ice departure and the elevation of the land. Subsequent terracing has removed half that amount.

The course of the Catskill at Leeds, where it crosses a ledge of hard Corniferous limestone is probably of postglacial superimposed origin, but the preglacial valley cannot be definitely fixed. H. B. K.

Geological Survey of Alabama.—Bulletin 4. By C. WILLARD HAYES. (Report of the Geology of Northeastern Alabama and Adjacent Portions of Georgia and Tennessee).

This report covers an area of 5950 miles, two-thirds in Alabama. Topographically it falls into three divisions: 1) the Cumberland and other plateaus of the northwest; 2) in the center, anticlinal valleys — Browns and Wills, with the synclinal mountains — Sand and Lookout; 3) the monoclinal mountains, the "flatwoods" (Coosa shales) and the chert hills (Knox limestone) of the southeast. The drainage of the first is radial from the center of the plateau to the Tennessee; that of the second, once consequent upon the folded structure, is now adjusted to the strike of the soft beds.

The formations are Cambrian, Silurian, Devonian and Carboniferous. Total thickness is from 13,000 to 18,000 feet in the east, but decreases westward. Hard sandstones of the Carboniferous form the cappings of the plateaus and synclinal mountains. In the anticlinal and monoclinal valleys the Silurian and Cambrian appear. The rocks pass from the nearly horizontal beds of the plateau region, by narrow unsymmetrical anticlines with steeper dip on the northwest side, and by broad shallow synclines, to the complicated folds of the southeast. The axes of these latter folds dip more or less abruptly northward and southward, causing the ridges to assume zigzag courses. Synclines are often crossed by anticlines.

Thrust faults exist, some of great magnitude, and traceable for 200 to 300 miles. By the "Rome thrust fault" the Cambrian shales have been shoved four to five miles over upon the Carboniferous shales. Most of the over-

thrust strata have been worn away, but tongues of Cambrian shale still remain to all appearances lying conformably upon the Carboniferous strata. Transverse thrust faults terminate Gaylor's ridge, Dirt Seller Mountain, and Lookout Mountain on the south. H. B. K.

The Correlation of Moraines with Raised Beaches of Lake Erie. By FRANK LEVERETT, U. S. Geol. Surv. (Wisconsin Academy of Science. Vol. VIII., 1891).

References have been made in Geological literature to the beaches of the eastern portion of the Lake Erie basin, but up to the time of Mr. Leverett's work none of the beaches had been completely traced. Mr. Gilbert had discovered that several of the raised beaches do not completely encircle Lake Erie, and supposed that their eastern termini represent the successive positions of the front of the continental glacier during its retreat northeastward across the Lake Erie basin. Mr. Leverett verifies this theory by demonstrating that certain moraines are the correlatives of the beaches. They are as follows:

I. The Van Wert or upper beach and its correlative moraine, the Blanchard ridge. II. The Leipsic or second beach and its correlative moraines. III. The Belmore, or third beach and its correlative moraine.

I. The Van Wert beach extends eastward from the former southwestward outlet of Lake Erie near Fort Wayne, Indiana, to Findlay, Ohio, where it joins the Blanchard moraine. Through Indiana and Ohio its altitude is quite uniformly 210 feet above Lake Erie.

While the Van Wert beach was forming, the ice front was the northeastern shore of the lake as far east as Findlay, Ohio, its position being marked by the Blanchard moraine. East of Findlay, where the Van Wert beach joins it, the moraine is of the normal type. But west of Findlay, it presents peculiarities of topography and structure, resulting from the presence of lake water beneath the ice margin. The water was shallow and incapable of buoying up the ice-sheet, and producing icebergs. The motion of the water under the ice-sheet produced a variable structure. This is the only instance of a moraine demonstrably formed in lake water.

II. The Leipsic, or second beach, was formed after the ice had retreated from its position marked by the Blanchard moraine. Its altitude is 195 to 200 feet above Lake Erie. It has its terminus near Cleveland, where it connects with the western end of a moraine.

III. The Belmore beach and its correlative moraine. Between the Leipsic beach and the present shore of Lake Erie are several beaches. One of these, the Belmore beach, terminates near Cleveland, while the others extend into southwestern New York, and probably connect with moraines, though this connection has not been traced. The general altitude of the Belmore beach in Ohio is 160 to 170 feet above Lake Erie. Unlike the Van Wert and

Leipsic beaches, it does not directly connect with a moraine at its eastern end, but a gap of ten miles intervenes. Terraces at Cleveland, Mr. Leverett thinks, make a connection between the eastern end of the beach and the western end of the moraine at Euclid, Ohio. C. E. P.

The Climate of Europe During the Glacial Epoch. By CLEMENT REID. (Natural Science. Vol. I, No. 6, 1892).

Temperature of the Sea. — The temperature of the English Channel was similar to that where the isotherm of 32° F. is now situated. The winter temperature can scarcely have been 20° colder than at present. The Mediterranean was perhaps 5° colder than now.

Temperature of the Land (air). — It does not appear that the climate of the lowlands of southern Europe can have been 20° lower than the present mean; 10° or perhaps less appear to have been the refrigeration in the Mediterranean region. The temperature at the southern margin of the ice-sheet was about 20° colder than at present. The temperature increased rapidly towards the south. Recent observations seem to show that throughout central Europe there was a period of *dry* cold, causing the country to resemble the arid regions of central Asia. J. A. B.

On the Glacial Period and the Earth-Movement Hypothesis. By JAMES GEIKIE, Edinburgh, Scotland. (Read before the Victoria Institute, London).

Geologists generally admit that there have been at least two glacial epochs, separated by one well-marked interglacial period. The closing stage of the Pleistocene period was one of cold conditions in northwestern Europe, accompanied by land depressions. After this came a genial climate with a union of the British islands among themselves and also with the continent. This was followed by a cold, humid condition.

Upham maintains that the whole of North America north of the Gulf of Mexico stood at least three thousand feet higher at the beginning of the glacial epoch than at present. Fiords were formed before glacial times and so can not be cited as evidence of high land during the glacial period. An elevation of land in the northern part of North America and Europe could not produce glaciation in their southern parts. The deflection of the Gulf Stream by the sinking of the Panama, Professor Giekie argues, could not produce the conditions which prevailed during the glacial epoch. The Earth-Movement hypothesis, he believes, accounts neither for the widespread phenomena of the ice-age, nor for the remarkable interglacial climates. Some maintain that the warm interglacial period was produced by the rise of the Panama land, the sinking of the lands to the north, and the turning of the Gulf Stream from the Pacific into the Atlantic. Why then, asks Professor Geikie, do we not have such a climate now? J. A. B.

Acknowledgments.

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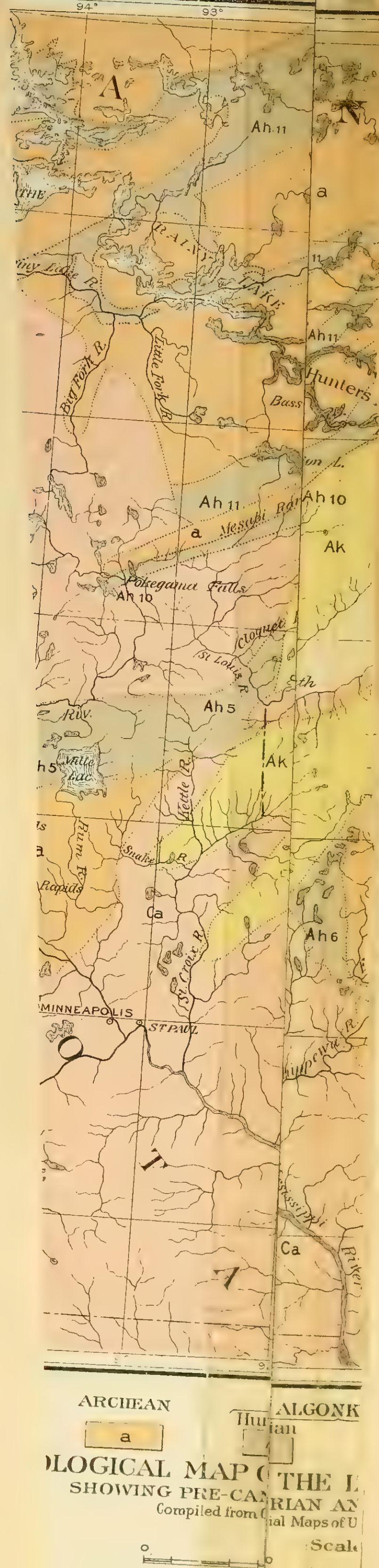
(Further acknowledgments of pamphlets and of specimens will be made in the next issue.)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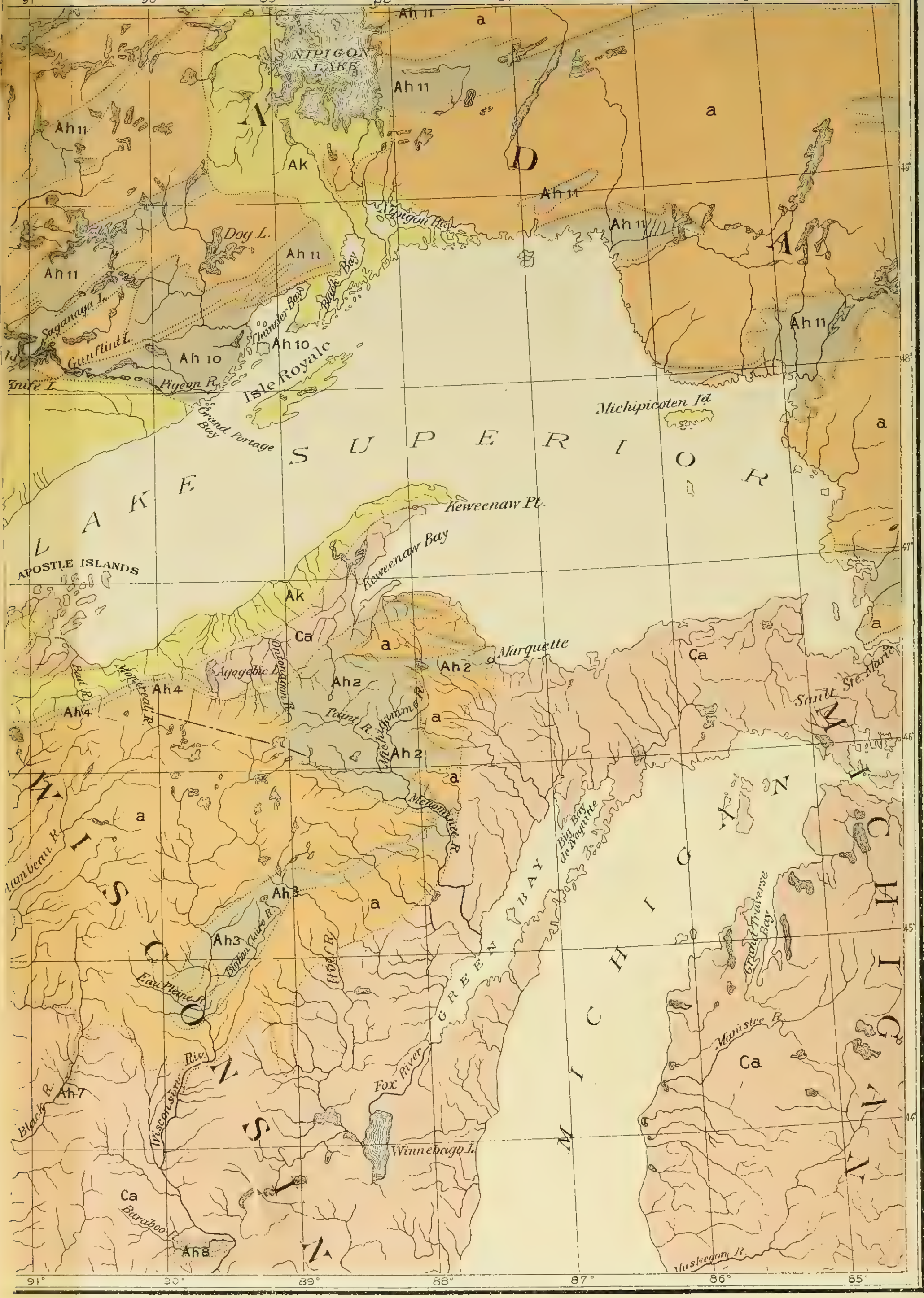

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AKE SUPERIOR REGION
ND CRYSTALLINE ROCKS.
.S. and Canadian Surveys.

100 150 STAT. MI.

HURONIAN

- Ah *The Original Huronian.*
- Ah 2 *The Marquette – Menominee Iron-Bearing Schists.*
- Ah 3 *The Wisconsin Valley Slates.*
- Ah 4 *The Penokee Iron-Bearing Schists.*
- Ah 5 *The St. Louis Slates.*
- Ah 6 *The Chippewa Valley Quartzites.*
- Ah 7 *The Black River Iron-Bearing Schists.*
- Ah 8 *The Baraboo Quartzites.*
- Ah 9 *The Sioux Quartzites.*
- Ah 10 *The Animikie Series.*
- Ah 11 *Folded Schists of Canada.*

THE

JOURNAL OF GEOLOGY

FEBRUARY-MARCH, 1893.

AN HISTORICAL SKETCH OF THE LAKE SUPERIOR REGION TO CAMBRIAN TIME.[1]

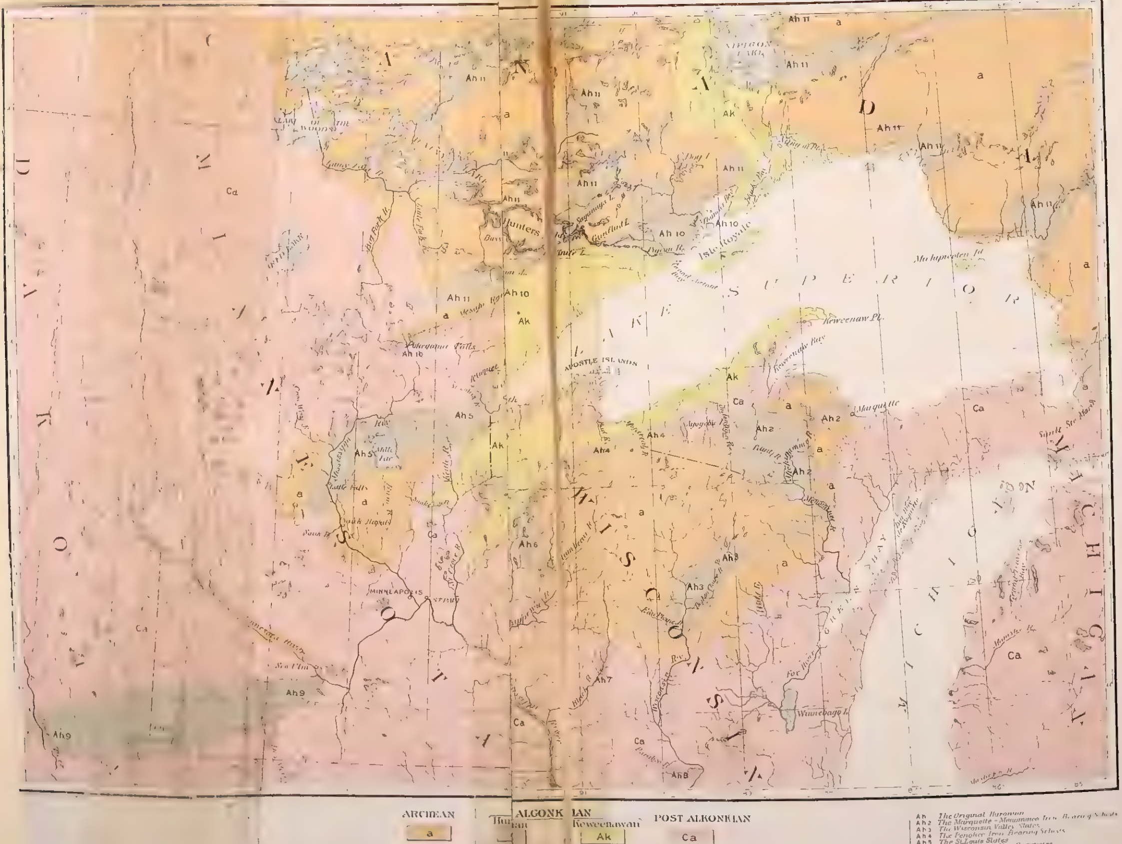
(WITH PLATE I.)

THE ancient formations south of Lake Superior may be grouped into five great divisions: the Basement Complex, the Lower Huronian, the Upper Huronian, the Keweenawan, and the Lake Superior Sandstone. These five divisions are separated by unconformities of great magnitude, two of them at least being of the first order. According to the classification adopted by the United States Geological Survey, the Basement Complex is Archean; the Lower Huronian, Upper Huronian and Keweenawan constitute the Algonkian for this region; and the Lake Superior Sandstone is Cambrian.

The Basement Complex.—The characteristic rocks of the Basement Complex are (1) light colored granites and gneissoid granites, and (2) dark colored finely foliated or banded gneisses or schists. These are cut by various basic and acid intrusives, many of which are not different from eruptives

[1]In this very general article no attempt will be made to give references to the many authors from whom facts are taken. To give full credit for all information used would require citations from scores of papers. The writer gives a summary of the literature of the Lake Superior Region in Bulletin 86 of the U. S. Geol. Survey.

Many of the problems considered have no definite answers as yet. The aim of the article is to give a summary of the very limited knowledge available on a subject that has not before been considered, because the data were not at hand upon which to base any reliable conclusions.



GEOLOGICAL MAP OF THE LAKE SUPERIOR REGION
SHOWING PRE CAMBRIAN AND CRYSTALLINE ROCKS.
Compiled from Official Maps of U. S. and Canadian Surveys

found in the later series, with which they are doubtless in part continuous.

The granites and gneissoid granites are placed together, because between the two are constant gradations. If one speaks accurately and includes among granites only those rocks which are completely massive, the gneissoid granites include the greater part of the granitic rocks; for in large exposures it is usually possible to find some evidence of foliation. The granitoid areas are of greatly varying sizes, running from small patches to those many miles in diameter. When everywhere surrounded by the schistose division of the Basement Complex, they frequently have oval or ovoid forms. In nearing the outer border of the granitoid areas, the foliation often becomes more and more prominent, and near the edge of an area the rock frequently passes into a well laminated gneiss.

The schistose rocks include fine grained hornblende-gneisses, mica-gneisses, chlorite-gneisses, and various green schists, formerly supposed to be sedimentary, but now known to be greatly modified basic and acid igneous rocks. These schists have usually a dark green or black color, are strongly foliated, and the variations in strike and dip of this foliation, within small areas, is very great. Not infrequently the schistose rocks are traced by gradations into massive igneous rocks.

The contacts between the schistose division and the granitoid division of the Basement Complex are usually those of intrusion, the granitoid rocks being the later. In passing from a schistose to a granitoid area, small pegmatitic looking veins of the granite are first found. In going onward these veins become more numerous and, after a time, unmistakable dikes of granite appear, which multiply in number and size in approaching the granite area, until the granite is found in great bosses. Here we have perhaps a nearly equal quantity of schistose and granitoid rocks, and in this intermediate zone the schists may be found as a mass of blocks within the granite, sometimes at but small distances from their original positions, the whole having frequently a somewhat conglomeratic appearance. However, these pseudo-

conglomerates, so well described by Lawson, grade more or less rapidly on the one hand into the schists, and on the other into the solid gneissoid granite. The complete change may occur within a short distance, or it may take a mile or more.

The Basement Complex is then composed of intricately interlocking areas of granitoid rocks and schistose rocks. Moreover, all of these rocks are completely crystalline. None of them show any unmistakable evidence of having been derived from sedimentaries, but many can be traced with gradations into massive rocks, and therefore the greater proportion of them are igneous, if a completely massive granular structure be proof of such an origin.

The Basement Complex is the most widespread of any of the Lake Superior systems, and it doubtless runs under all later formations to a greater or lesser distance. That it is continuous under all such formations can not be asserted, for while it was once so, it is possible, perhaps even probable, that in places, as a consequence of sedimentation and folding, the Basement Complex has been so deeply buried, that fusion has locally resulted. It is even possible that such fused material is a partial source of the later volcanic eruptions.

Before the earliest sedimentary rocks were deposited, the Basement Complex was subjected to enormous orographic forces, which folded and sheared the rocks in a most intricate manner. Accompanying the great orographic movements, which undoubtedly occupied a vast period of time, were intrusions of various deep seated igneous rocks, and also doubtless their volcanic equivalents were extruded. Subsequent to, and during the orographic movements, atmospheric forces were at work. Erosion continued long after the mountain-making folding had ceased, and, for much of the Lake Superior region, reduced the Basement Complex nearly to a plain or base level. As evidence of this may be cited the fact that, at the end of the erosion interval, the Basement Complex, consisting of differing lithological materials, and therefore having a variable resisting power, did not vary in altitude more than a few hundred feet for long dis-

tances. Whether this denudation extended everywhere deep enough to remove all surface volcanic material, and to leave only deep seated igneous material, is undetermined. At the beginning of the Lower Huronian time, the Basement Complex was, in the Lake Superior región, a universal system.

The Lower Huronian.—After the forces of erosion had nearly exhausted themselves, there was the first advance of the sea over the Lake Superior region of which we have any evidence, as a result of which the Lower Huronian was deposited.

The well-known characteristic rocks of the Lower Huronian, are (1) conglomerates, quartzites, quartz-schists and mica-schists, (2) limestones, (3) various ferruginous schists, (4) basic and acid eruptives, which occur both as deep seated and as effusive rocks. The order given, with the exception of the eruptives, is the order of age from the base upward.

The inferior formation is usually a quartzite or a feldspathic quartzite. Where metamorphism has been severe it passes into a quartz-schist, mica-schist or gneiss. The lowest horizon of the formation is in places a coarse conglomerate, and this when metamorphosed may become a conglomerate-schist. This conglomerate is of two types, depending upon the character of the underlying formation, which is here granitic and there schistic. The limestone formation, when at its maximum, is of very considerable thickness. The limestone is magnesian and so very crystalline as to make the name marble appropriate. It frequently contains a considerable amount of chert. In places it may be divided into two horizons, one of which is nearly pure marble, and the other nearly pure chert. At other times the limestone becomes very siliceous by a mingling of fragmental quartz, while zones of wholly fragmental material may occur. These impure phases are often at the lower part of the limestones, where they may be considered as a transition from the underlying formation. The formation overlying the limestone is usually known as the iron-bearing member, since it contains all the ore bodies of the Lower Huronian. It has varied aspects, but the different varieties grade into one another both vertically and

laterally, so that when one becomes familiar with them, the rocks of the formation may invariably be recognized. Here are included hematitic and magnetitic schists, cherts, jaspers, ferruginous carbonates, and other forms. The formation always differs from the limestone in carrying a very considerable amount of iron, and it differs from the quartzite in being largely, and sometimes wholly, a chemical or organic sediment, rather than a mechanical one.

The three members of the Lower Huronian are not often seen in a single section. This may be due to lack of exposures, but in some cases is undoubtedly due to the absence of one or more of the formations themselves.

In the Lower Huronian, basic eruptive rocks are abundant, and locally cover considerable areas. Not infrequently acid eruptives also occur. These eruptives include both contemporaneous volcanics and subsequent intrusives. If the Keewatin of Lawson about Rainy Lake and the Lake of the Woods is Lower Huronian, great granitic masses have been intruded into this series northwest of Lake Superior.

Equivalent to the Lower Huronian series of the north shore of Lake Huron are placed the following iron-bearing districts: Lower Vermillion, Lower Marquette, Felch Mountain, in large part, Lower Menominee, the cherty limestone formation of the Penokee district; and probably the Kaministiquia series of Ontario, and the Black River Falls series of Wisconsin. Whether all of these detached basins were once connected by continuous sediments is unknown, but probably they were.

The fragmental material of the Lower Huronian was derived from the Basement Complex. This fragmental formation is usually thin. This doubtless means that the advance of the sea over the Lake Superior region was comparatively rapid. The directions from which the Lower Huronion sea entered, and the extent of its trangression, is at present unknown. By certain of the Canadian geologists it is held that the structural break which exists between the Basement Complex and the Lower Huronian, south of Lake Superior and north of Lake Huron, does not exist

in the region of Rainy Lake and Lake of the Woods, northwest of Lake Superior. If this conclusion be true, the sea did not advance as far as the Lake of the Woods, this district perhaps being above the ocean, and one of the sources of detritus throughout Lower Huronian time.

The extent of the Lower Huronian deposits is also uncertain. If the series of the districts above placed in the Lower Huronian, are correctly correlated, Lower Huronian basins occurred in various places over a great triangular area extending from Black River Falls in Wisconsin, to northeastern Minnesota, and thence east to the north shore of Lake Huron. Doubtless Lower Huronian rocks also occur in the great northern region of Canada, and they may have had a much wider original extent than this, but no data are now available to locate such a possible extension.

Of the original thickness of the Lower Huronian deposits we are also ignorant. The present thickness has not been determined south of Lake Superior, but according to Logan, on the north shore of Lake Huron, including the interstratified volcanics, the thickness is five thousand feet.

At the end of Lower Huronian time, the Lake Superior region was raised above the sea, folded, and subjected to erosion. The orographic movements of this time were very severe, closely crumpling in places the rocks of the Lower Huronian, and inducing in them in many places a schistose structure. In other localities, away from the axes of great disturbance, the Lower Huronian rocks were but gently tilted, as is shown by the small discordance in places between them and the succeeding series. In certain localities the areas of great disturbance are but a short distance from those of comparative quiet. The denudation was deep enough to wholly remove the entire series over wide areas, and to cut to unknown depths into the Basement Complex itself. As has been stated, the Lower Huronian has an estimated thickness of about one mile on the north shore of Lake Huron, and in different localities varies from this thickness to entire absence, depending mainly upon the differing deundation. This variabil-

ity may possibly be due in part to highlands of the Basement Complex, which were not covered by the Lower Huronian sea until the period was well advanced. Of the extent of the series at the end of the erosion preceding Upper Huronian deposition, little has been determined, since later erosions have undoubtedly removed large areas of the series, and therefore its present distribution is not a safe guide to its distribution at the close of the erosion interval referred to.

The Upper Huronian.—At the close of the long period of erosion which followed the Lower Huronian deposition, the water once more advanced upon the Lake Superior region, and the Upper Huronian series was deposited.

Lithologically this series consists of conglomerates, quartzites, graywackes, graywacke-slates, shales, mica-schists, ferruginous slates, cherts, jaspers, ferruginous schists and igneous rocks, including both lava flows and volcanic fragmentals, as well as basic and acid intrusives. The series, as a whole, is very much less crystalline than the Lower Huronian, although locally the shales and graywackes have been transformed into mica-schists, and even into gneisses.

The Upper Huronian immediately about Lake Superior is divisible into three formations, a lower slate, an iron-bearing formation, and an upper slate, the basis of separation being that of mechanical and non-mechanical detritus. The inferior formation is mainly a quartzose slate or shale, but locally it passes into a quartzite, while the basal horizon is frequently a conglomerate. The nature of this conglomerate varies greatly, depending upon the character of the underlying formation, which, in some areas, is the Basement Complex, and in others the Lower Huronian. In the first case the slates may rest upon the gneissoid granite, upon the schists, or upon the junction of the two. The basal conglomerate corresponds in its character, being a recomposed granite or granite-conglomerate, a recomposed schist or schist conglomerate, or finally a combination of the two.

When the lowest member of the Upper Huronian rests upon the Lower Huronian series, the underlying formation may be

any one of the three formations of the Lower Huronian. As a consequence the basal conglomerate may consist mainly of the fragments of any one of these formations, or of all of them together. Not infrequently detritus, derived from the Basement Complex, is mingled with that of Lower Huronian origin. However, as a consequence of the resistant character of the jaspery iron-bearing formation of the Lower Huronian and of mining operations, the discovered contacts are most frequently between the Upper Huronian and this iron-bearing formation. In the basal conglomerate or recomposed rock at these points, the characteristic fragments are chert, jasper, and other ferruginous materials, and it is locally so rich in iron as to bear ore-bodies. The uppermost horizon of the lower slate of the Upper Huronian in the Penokee district is a pure, persistent layer of quartzite. The central mass of the formation is a graywacke or graywacke-slate, passing in places into a shale or sandstone.

Above the lower slate is the iron-bearing member, consisting of various ferruginous rocks, including cherts, jaspers, magnetite-actinolite-schists, iron ores, and ferruginous carbonates. It has been shown that all these varieties have been mainly derived directly or indirectly by transformation from an original lean, iron-bearing carbonate, which was of chemical or organic origin, or a combination of both. Mingled with these non-mechanical sediments is a greater or lesser quantity of mechanical detritus.

Above the iron-bearing formation is the upper slate formation. This is mainly composed of shales frequently carbonaceous or graphitic, slates, graywackes and mica-schists, often garnetiferous and staurolitic. The mica-schists are usually toward the upper part of the formation. The stages of the transformation between these crystalline rocks and plainly fragmental detritus have been somewhat fully made out .

The lower slate formation is of variable thickness, but is usually less than a thousand feet. The iron-bearing formation is also of very variable thickness, its maximum being perhaps about the same as that of the lower slate, and from this it varies to disappearance, the horizon being usually represented, however, by

carbonaceous and ferruginous shales and slates. The upper slate formation includes the great mass of the Upper Huronian series. Its maximum thickness is more than ten thousand feet.

In certain areas, during Upper Huronian time, there was great volcanic activity, as a result of which, peculiar formations were piled up, wholly different from any of the ordinary members of the series. Also this volcanic activity greatly disturbed the regular succession, so that for each of the volcanic districts an independent succession exists, the sedimentary and volcanic formations being intimately interlaminated. The two areas which are best known are the Michigamme iron district north of Crystal Falls and the east end of the Penokee district. Similar volcanics also occur in the Marquette district. In the Michigamme iron district is an extensive area of greenstones, greenstone-conglomerates, agglomerates and surface lava flows, many of which are amygdaloidal. In the Penokee district the materials are almost identical. The typical succession for this district extends in unbroken order for fifty miles or more, but east of Sunday Lake this is suddenly disturbed by the appearance of the volcanics. The character of the rocks and their order soon becomes so different that if one were not able to trace the change from one into the other, there would be a great temptation to regard the part of the series bearing volcanics earlier than or later than the Penokee series proper. But the continuity of the two cannot be doubted. Thus this occurrence well illustrates that lithological character in pre-Cambrian, as in post-Cambrian time is no certain guide as to relative age. Finally, associated with the Lake Superior Upper Huronian rocks are many later intrusive dikes and interbedded sills, chiefly diabases, gabbros and diorites, but local granitic intrusives also occur, particularly in the Felch Mountain and Crystal Falls districts, and possibly also in the Menominee district.

The typical districts in which the Upper Huronian series can be best studied are the Penokee, Marquette, Mesabi and Animikie. Remote from the Lake Superior region proper, the rock series

which are correlated with the Upper Huronian have not the same successions of formations as in these districts. The Upper Huronian north of Lake Huron has a set of formations which can not be correllated with the formations above given; the same is true of other series to the south which are here placed. The position of these latter as a part of the Upper Huronian must not be considered as a question finally determined, but rather as representing the probability, from the weight of evidence at the present time. It can not be expected that in a great geological basin the same subordinate succession of formations will be everywhere found.

However, for the present, regarding all these series as Upper Huronian, this is the most widespread of the Lake Superior pre-Cambrian sedimentary series. It includes a great area, extending from the Sioux quartzites of Dakota on the southwest, to the Huronian rocks north of Lake Huron on the east, and thence far to the north, and from Lake Huron to the Animikie series of the National Boundary west of Lake Superior. Within this area are included the major portion of the Baraboo quartzites of Wisconsin; the major portion of the large area in the Upper Peninsula of Michigan, the eastern arms of which are the Menominee, Felch Mountain, and Marquette iron-bearing districts; the greater part of the Penokee-Gogebic iron-bearing series of Michigan and Wisconsin; the Chippewa quartzites of Wisconsin; St. Louis slates of Minnesota including the newly developed Mesabi range of Minnesota, and the Animikie series of Thunder Bay, Lake Superior and its westward extension. That most, and perhaps all of these areas were once connected, there can be no reasonable doubt.

This broad semicircular zone of Upper Huronian rocks, extending from the National Boundary west of Lake Superior through Ontario, Minnesota, Michigan and Wisconsin, to the north Channel of Lake Huron, and thence north to the east side of James Bay, suggests that the transgression of the sea was from the south and east, and that the source of the mechanical detritus is the great expanse of so-called Laurentian rocks west of Hudson

Bay and north of Lake Superior. How far the sea transgressed over this area, and whether it also advanced toward it from the north and west, is unknown. It is probable as the sea advanced from the south, that the great mass of fragmental detritus, making up the Baraboo and Sioux quartzites, was laid down before the sea had transgressed to what is now the north shore of Lake Superior, and thus would be explained the discrepancy in the parallelism of formation between the Sioux quartzites, Baraboo quartzites, etc., and the districts of Upper Huronian rocks adjacent to Lake Superior.

In this case the advancing ocean was perhaps making its progress by cutting a terrace quite as much as by subsidence. However, there is reason to believe that the area included within the west end of the Lake Superior Basin, *i. e.*, from the Animikie series to the Mesabi range, and thence to the Penokee series was submerged practically at the same time. For here we have three great formations of like character in identical order. The lowest formation, the quartzite and quartz-slate with conglomerates derived from the Basement Complex and the Lower Huronian, are the first deposit of the advancing sea. After this came a deepening of the water, when the calcareous and ferruginous formation, now constituting the iron-bearing member, was laid down. Then perhaps as a consequence of the upbuilding of this formation, came a shallowing of the water and the deposition of the great thickness of clayey sediments of the Upper Huronian. Since the last formation must have been deposited in shallow water, and yet is of great thickness, the bed of the ocean was probably subsiding during the remainder of Upper Huronian time.

At the end of the deposition of the Upper Huronian rocks, the Lake Superior region rose above the sea, and the atmospheric forces once more set to work. The orographic movement following the Upper Huronian, like that following the Lower Huronian, was locally intense, but in general the folding was of a gentle character. Along narrow axes the plications were so severe as to give the Upper Huronian rocks a foliated structure and com-

pletely crystalline schistose or gneissic character, but for the most part the changes in the Upper Huronian rocks are those of cementation and metasomatism. As with the Lower Huronian areas of intense plication, they are sometimes but short distances from those in which the rocks have been merely tilted.

How deep the Upper Huronian denudation went it is impossible to say. We only know that at a maximum, the Upper Huronian rocks are now 13,000 feet thick, and in certain other places are entirely absent, the higher members disappearing first and the lower members last. Thus the difference of the Upper Huronian denudation is measured by 13,000 feet. To this must be added the unknown thickness of the Upper Huronian rocks, which have been wholly swept away, and the thickness of the Lower Huronian and Basement Complex, which were cut at this time. The thickness represented by these three elements is unknown, but it is probably great.

Of the outer limits of the Upper Huronian transgression, we are as ignorant as of the preceding ones, but certain it is that it had an extent to the outer areas mentioned as belonging to this series. Beyond these limits no knowledge is available. The original extent to the east, south and west of the Upper Huronian will probably never be determined, since the ancient rocks are covered by the Cambrian and post-Cambrian sediments. Whether the transgression extended over the Great Northern area of Canada to the Paleozoic deposits will doubtless be ascertained when this vast region is studied in detail.

The Keweenawan.—Again a change of conditions occurred, and a great flood of basic volcanics, in beds of enormous thickness were poured out. Later these were followed by more thinly bedded volcanics. At about the same time a portion, at least, of the Lake Superior region became immersed in the sea, since in places the basement lavas of the Keweenawan are interstratified with sandstone and conglomerates.

The Keweenaw series is composed lithologically of gabbros, diabases, porphyrites, amygdaloids, felsites, quartz-porphyries, etc., and of sandstones and conglomerates. The basic and acid

rocks constituting the series are mainly surface flows. The gabbro flows are often of immense thickness. The diabase flows are usually much thinner, and frequently pass in their upper parts into porphyrites and amygdaloids. Many flows are porphyritic or amygdaloidal throughout. The beds of quartz-porphyry and felsite are abundant in certain districts, but usually have no great lateral extent, but while a single flow may be traced but a little way, frequently a group of flows of the same general character may have a great extent and thickness. But even the groups of flows cannot be regarded as general formations for the whole of the Lake Superior basin.

Since the number and thickness of the volcanic beds as well as the detritals vary greatly, the Keweenaw series as a whole is widely variable in different districts in its character and thickness. Structurally, Irving has divided the series into two parts, a lower division, in which eruptives are present, and an upper division, in which eruptives are absent. In any one section of the Keweenawan, at the lower part of the lower division, are generally found numerous volcanic flows, with few or no detrital beds. In passing toward the middle of the series the sandstones and conglomerates become more and more numerous and of greater thickness. Still higher the sandstones and conglomerates become predominant, and finally volcanic products disappear, the upper ten or fifteen thousand feet of the Keweenaw series being wholly composed of mechanical detritus. A given detrital bed varies from a mere seam of narrow local extent to thick beds of sandstone and conglomerate, one of which has been traced by Marvine for more than one hundred miles. The most general detrital formation is the upper sandstone and conglomerate.

The Keweenawan rocks extend about the entire area of the Lake Superior basin. They appear upon the east shore of Lake Superior, cover a large area of Keweenaw Point, northern Wisconsin, eastern and northeastern Minnesota, and a great area about Lake Nipigon. A similar set of volcanics, occupying a like stratigraphical position, is also known adjacent to Hudson Bay, and this may be a contemporaneous series.

The Keweenawan is the thickest of the series about Lake Superior, its maximum being estimated by Irving at the Montreal river to be fifty thousand feet. From this thickness it varies to nothing. This vast quantity of material does not, however, of necessity mark a period longer or perhaps even as long as the Lower Huronian or Upper Huronian, for the greater part of it is of igneous origin. The lava flows in their extent and thickness are to be compared with the great volcanic plateaux of the far West, rather than with local volcanoes such as Vesuvius, or the local volcanoes of the Upper Huronian and Lower Huronian. Associated with the lavas no volcanic fragmental material has been as yet discovered.

The source of the lavas of the Keweenawan is beyond the scope of this paper. It was, however, suggested that the fusion of a portion of the Basement Complex, and even Lower Huronian, may have in part produced the deep-seated magmas, the extrusion of which produced the Keweenawan lavas.

In large measure the sandstones and conglomerates derived their materials from the volcanics of the series, but a lesser quantity came from earlier series. This latter is particularly true of the great detrital formation constituting the topmost member of the Keweenawan. Partly because fragments derived from the felsites and porphyries are more resistant than those from the basic rocks, acid pebbles are relatively abundant in the conglomerates.

The fact that erosion was contemporaneous with eruption for much of Keweenawan time is to be noted. Certainly, when the period was well inaugurated, most of the Lake Superior basin was normally below the sea or near tide water. Many of the eruptions may have been sub-aqueous. Here and there volcanic masses of such magnitude were built up as to rise above the water, and upon such areas, the sea at the base, and the air and rain above, immediately began their course of destruction. The acid and more viscous lavas may have formed the more prominent elevations, and thus the attack was here more vigorous. This may partly explain the predominance of the acid pebbles in the conglomerates.

This great volcanic period was doubless one of unstable equilibrium, the lithosphere falling here and rising there. One of the final movements was the production of the Lake Superior synclinal. This synclinal movement affects not only the Keweenawan rocks, but the lower series, and in areas in which the unconformity between the Upper Huronian and the Keweenawan is not great, there is such a likeness in strike and dip of the two series as to suggest, at first, that the two are conformable. It is only as the contacts between them are followed for some distance, and the Keweenawan is seen to be now in contact with one member of the Upper Huronian, and now with another, that it is perceived that between the two there is an unconformity.

What proportion of the Keweenawan had accumulated before this Lake Superior synclinal began it is impossible to say. Possibly somewhere near the center of the Lake Superior basin were the larger foci, from which the great extrusions of lava occurred, and here a simultaneous sinking went on, such as is usual as a result of the upbuilding of a mountainous mass of volcanic material. This suggestion, if true, would also partly explain the apparent absence of volcanic fragmental material which naturally would accumulate near these foci.

Nowhere are the Keweenawan rocks so closely folded as to give them a schistose structure or a metamorphic character. Their induration is almost wholly a process of cementation.

The Cambrian Transgression.—At the close of Keweenawan deposition the Lake Superior region was again raised above the sea, and the pre-Cambrian erosion continued until the enormous thickness of Keweenawan deposits was wholly truncated. What must have been mighty mountains were reduced to mere stumps, or to base level. Following this denudation, the sea once more transgressed upon the land, and the horizontal Lake Superior sandstone was deposited. It now occupies many of the bays about Lake Superior. It once was much thicker, and perhaps covered all but the highest points of land. Certainly it or an overlying formation once was at least one thousand feet higher

than the level of Lake Superior, but it has since been almost completely removed, so that it occurs only in patches within the depressions of the older rocks.

Since Cambrian time no important orographic movements nor outbursts of volcanic material have occurred in the Lake Superior region, consequently the rocks have received little subsequent alteration. To these facts is due the possibility of outlining the pre-Cambrian history of this area with greater fullness than has been done in areas in which later disturbances have obscured the early history.

C. R. Van Hise.

THE GLACIAL SUCCESSION IN OHIO.

In Ohio, as in other portions of the Mississippi basin, clear and unmistakable evidence of discontinuity in the drift deposition has long been recognized. Whittlesey, Newberry and Orton were among the first to announce the occurrence of buried soils in the North American drift, and they each drew illustrations from Southwestern Ohio. A few years later Professor Chamberlin discovered evidences of late advances in which the outline of the ice-sheet was very different from that of the glacial boundary. He also observed that the aspect of the drift is much fresher than in the outlying earlier drift. He further noted the evidence of valley erosion of considerable amount effected in the interval between the formation of two moraines, or more accurately two sets of moraines, in Western Ohio, the oldest of which is much younger than the earliest drift sheet, as will be seen below. My own studies, carried on under the direction of Professor Chamberlin, have brought out more fully the nature and value of these and other intervals which exist in that region. No less than nine of the twelve criteria for discrimination between glacial epochs set forth by Professor Salisbury in the opening number of this Journal have been found, viz.: (1) Buried soils. (2) Buried fossiliferous silts. (3) Differential weathering. (4) Differential subaërial erosion. (5) Excavation of valleys between successive depositions of drift. (6) Changes in the course of ice-currents and in the outline of the ice margin. (7) Superposition of drift of different physical constitution. (8) Varying altitudes of the land. (9) Variations in vigor of ice action. Although the present state of knowledge of the Ohio drift is far from being as complete as one could desire, it seems profitable to review such evidence as throws light upon the value of the several intervals which mark the glacial succession in that state. In the western portion of


MAP OF THE
MAUMEE-MIAMI GLACIER
BY FRANK LEVERETT
0 5 10 15 20 25
Scale of Miles
OHIO
KY.
GLACIAL BOUNDARY
ERIE

EXPLANATION OF MAP.—This map was designed for another purpose, and hence includes only a portion of the district under discussion, though it represents the principal features herein discussed. Certain features, not discussed at this time, beach lines, eskers, esker troughs, etc., appear on the map.

The shaded portions of the map represent moraines, the shading being graduated to the strength of the moraine. Arrows indicate the position and bearing of striæ. Continuous lines are used to indicate the beaches of the Maumee basin and the south-western outlet of the lake which formed them. The second beach has not been fully traced, and is therefore incompletely represented. For the same reason the fourth and later beaches are not represented. Esker troughs are bounded by broken lines. The eskers which lie in them are indicated by continuous straight lines. The boundaries between upland and lowland tracts in southern Ohio are indicated by dotted lines. The glacial boundary, indicated by a broken line, appears for a short distance in the vicinity of Cincinnati.

the state there is a more complete and more easily deciphered record of the glacial succession than in the eastern portion, since the later advances there left a portion of the earlier drift uncovered. Our remarks will, therefore, relate chiefly to that district.

The full series of moraines formed by the Great Miami ice lobe, together with portions of the outer moraines of the adjoining East White River lobe on the west, and of the Scioto lobe on the east, are shown on the accompanying map. Outside the outer moraine of these lobes there is a glaciated district extending southward beyond the limits of the map in the main, its southern margin being the glacial boundary which lies fifteen to forty miles south from this moraine. That a long interval elapsed between the deposition of this outlying drift sheet and the formation of the outermost frontal moraine is shown below. Attention is called to it at this point, since it furnishes a convenient landmark in our discussion. The drift to the north of this moraine will be called, for convenience, by the general term, the later drift, while that to the south will be called the earlier drift. Both drifts have a somewhat complex history, and will be subdivided further on.

The earlier drift. For a few miles back from the glacial boundary in Northern Kentucky and in the hilly districts of

Highland, Adams and Brown counties, Ohio, there is a discontinuous or patchy deposit of drift, consisting in places only of scattering bowlders. In other places it consists of a clayey or sandy deposit, in which a few erratics are imbedded. In still others, notably at Split Rock and along Middle creek, west of Burlington, Kentucky, it consists of cemented coarse gravel. Only occasionally in the border portion is there a deposit of thoroughly commingled drift or typical till such as characterizes the thicker drift sheet immediately north. The attenuation seems due more largely to original deposition than to subsequent erosion.

Over the greater part of this earlier drift district back from the attenuated border one finds a nearly continuous deposit of till ranging from a few feet up to one hundred feet or more in thickness. It displays little or no aggregation in morainic knolls or ridges. The greatest thickness is found in filled-up valleys or in depressions, though the uplands in places carry as much as fifty feet of drift. Where less than twenty feet in thickness this drift sheet consists in the main of a yellow till. Where the drift has greater thickness a blue till is commonly found beneath the yellow. The blue till abounds in joints or irregular fissures filled with yellow or oxidized clay, a feature which is rare in the later drift sheet, and may, perhaps, constitute an important line of evidence as to the age. Both the yellow and the blue till are harder than those of the newer drift. The indurated character of this earliest drift sheet is apparently due to a partial cementation with lime, the drift being highly charged with a calcareous rock flour, a glacial grist.

The earlier drift seems to have been deposited in this district without great abrasion of the rock surface. No striæ have been found, though repeated search was made for them. (In districts further west striæ are occasionally found beneath the earlier drift). Between the blue till and the underlying rock there are frequent exposures of a few feet of earthy material having the appearance of residuary clay, or, if this be absent, a very rotten rock surface is usually found. In one village (Mt. Oreb) well

sections are reported to have passed through a black mucky clay, probably a preglacial soil, immediately beneath the blue till and a few feet above the rock surface. This feeble abrasion is thought to be due to lack of vigor in the ice-movement. The attenuated border is apparently due to the same lack of vigor and to a comparatively short occupancy of the region by the ice-sheet. The lack of vigor in this earlier invasion is in striking contrast with the vigor of the invasion which produced the outer moraine of the Miami and Scioto lobes, there being numerous exposures of striation in the district immediately north of that moraine, while the moraine itself bears evidence that the ice-sheet had great shoving power.

There is a possibility that this earlier drift sheet embraces two distinct periods of deposition. Evidence in support of this view is cited by Professor Orton in his report on Clermont county, Ohio (the county bordering the Ohio river just above Cincinnati), viz., that a buried soil and deposit of bog iron occur at the junction between the yellow and blue tills. From Professor Orton's account it would appear that no marked oxidation of the surface of the underlying blue till had occurred before the yellow till was deposited. We infer from this that the interval of deglaciation may have been comparatively brief, though it is possible that swampy conditions, such as prevail in the production of bog iron, prevented oxidation during a prolonged period. Inasmuch as Professor Orton is a careful observer and cautious writer, I do not feel free to question the evidence he cites, but my examinations in this district have not confirmed his evidence, so far as the location of the soil bed at this particular horizon is concerned. I have found testimony as to the occurrence of buried wood at or near this horizon, but not of soil beds. Possibly Professor Orton considers the occurrence of wood good evidence of an old land surface, but in view of the fact that wood may be incorporated in the drift as a part of the glacial debris I have not thought this a sure evidence. In the lists given in the Ohio reports, Dr. Newberry cites instances of wood to prove the existence of a "forest bed," and forest

bed and soil are terms which are used interchangeably in the Ohio Geological Reports. It ought also to be stated in this connection that a few miles to the north a buried soil occurs beneath the till, but it lies within the district covered by a later invasion of the ice, and the horizon is, I am convinced, above that of the one in question. There is also a soil above the yellow till of this earlier drift sheet which is buried by a silt deposit, as described below. I feel, therefore, that it is necessary to refer to different horizons the instances that have been reported from south-western Ohio.

Deglaciation interval with development of a soil attended by oxidation, leaching and erosion of the earlier drift sheet. Except where erosion has removed it a capping of silt several feet in thickness is found upon the surface of this till sheet. It is clearly of much later age than the till, being separated from it by a sufficient interval for the development of a soil, and for a large amount of oxidization and leaching and erosion. This silt is discussed below.

The soil which was developed on this till sheet does not commonly show a black color, though exposures of such a soil color are met with in all parts of the district outside the outer moraine. The evidence of a land surface is more generally found in the deep brown color, and weathering or soil-producing disintegration of the upper part of the till. The deep brown changes gradually below to the ordinary yellow color of oxidized till, but at top it terminates abruptly at the base of the overlying silt. The color of the silt being much lighter than that of this brown soil the contrast is very marked. The deep brown color extends usually to a depth of two feet or more, while discoloration extends to six or eight feet. The amount of discoloration is somewhat greater than is commonly found at the present surface of the newer drift. Repeated comparisons of the soil in the two districts lead to the conviction that this older drift sheet had been exposed as a land surface for a longer time before the silt was laid upon it than has the outer moraine of the newer drift up to the present date. The same conclusion is reached

upon comparing the amount of leaching in the two districts. In the earlier drift sheet it is rare to get a response with acid within six to eight feet of the surface, whereas in the newer drift the leaching has seldom been carried to so great a depth as six feet. It seems clear from the position and relations of this old surface that the leaching took place before its burial.

Concerning the amount of valley erosion accomplished in south-western Ohio during this interval no conclusion was reached. Sufficient time was not given to the study of the region to successfully eliminate the effects of post-glacial erosion and of erosion accomplished between the deposition of the silt and the invasion which produced the older moraine of the later drift. In eastern Indiana, however, there are exceptionally favorable conditions for determining the amount of erosion accomplished between the deposition of the earlier and later drift sheets, and it is believed that data of some importance can be furnished. Near the head waters of the Whitewater river there is a district covered by a thick deposit of drift. We may judge from wells made on interfluvial tracts that the level of the rock surface in that region is no higher than the valley bottoms of the several headwater tributaries of West Whitewater, and these valleys are, therefore, simply channels cut in the drift. The evidence all opposes the view that the ridges and valleys are in any way dependent upon preglacial erosion. The valleys along these headwater tributaries of the West Whitewater (Noland's fork, Green's fork, and West fork) are conspicuous for their size, their width being one-fourth to one-half mile or more and their depth sixty to one hundred feet. A similar broad valley is occupied by the headwaters of East Whitewater, though this stream has, since the later ice-invasion, cut a narrow gorge down into the rock strata.

This district of eroded drift was overridden by the western edge of the Miami and the eastern edge of the East White River lobe of the later incursion, but it so happens that the amount of drift deposited does not greatly conceal the outlines of these old valleys, the general thickness of the later drift sheet in this region

being not more than thirty to forty feet. The outer moraine of the East White River lobe, after following an upland tract west of the West Whitewater northward for some distance, descends, near Cambridge City, into the valley of the West fork of West Whitewater, and after crossing this valley rises near Hagerstown onto elevated upland. The outer moraine of the Miami lobe also, in crossing Noland's fork, south-east of Cambridge City, descends into and is developed in the valley as well as on the bordering ridges. That the valleys were formed previous to the deposition of this moraine, there can be no doubt, and being made entirely in the drift, as noted above, they show clearly that their excavation must be confined to the interval between the deposition of the earliest drift sheet and that of this moraine. The amount of erosion is several times as great as that accomplished by the streams that have traversed this valley since the moraine was laid down. The size of the streams which formed them constitutes an important factor in determining the time required in this excavation. That these interglacial streams were not much larger than those now traversing this region, seems probable from the fact that within a few miles north from the sources of the present streams, the general slope of the country becomes northward, so that drainage would naturally be in that direction, instead of southward along the Whitewater. The erosion here displayed seems, therefore, to indicate the lapse of a longer interval between the deposition of the earliest drift sheet and that of the outer moraine of the later drift, than the time that has elapsed since the formation of that moraine. How much of this interval preceded the silt deposition, it is difficult to determine, because the outer moraine has concealed the silt. Light upon this question should be obtained upon careful study of the lower portion of the Whitewater valley and of other valleys lying within the silt-covered district and outside the moraine, but this line of study has not yet been undertaken.

Depression accompanied by silt deposition. The silt which is found on the upland outside this moraine, has been discussed at

some length, in a recent paper.[1] It need, therefore, be but briefly touched upon here. It is there shown that it forms a practically continuous sheet over the southern portion of the glaciated district in Ohio and Indiana, and extends to an undetermined distance over the unglaciated districts of Ohio. It also appears on the uplands in Kentucky, south-west of Cincinnati, and may appear further east in that state. It has been found along the margin of the glaciated district in Ohio as far north-east as the vicinity of Newark, but has not been observed farther north and east.

The thickness of this silt decreases in passing southward, especially on the interfluvial tracts of south-western Ohio and south-eastern Indiana, a fact which seems to indicate that its source was from the north rather than from flooded conditions of the Ohio river. From evidence gathered in the upper Mississippi region, it is thought to be the correlative of a sheet of glacial drift not exposed to view in these states, or at least not yet discovered. Its thickness in the northern part of the district, next to the outer moraine of the newer drift, is four to six feet or more while on the borders of the Ohio river it scarcely exceeds three feet, and in places is two feet or less. Wherever examined it is found to be thoroughly leached. This fact is thought to be of importance in showing great age, especially on the theory of the glacial origin of the silt, since glacial silts, as well as till, in regions underlain as this region is by limestone, contain a large amount of calcareous material.

The amount of depression involved in this subsidence is difficult to determine. As yet such data as have been discovered bearing upon the altitude of the land, either previous to or during the depression, are not precise, though it seems probable that the altitude was several hundred feet lower at the maximum of depression than at the present time, while before the depression the drainage appears to have been good, and we may suppose that the altitude was not much lower than at the present time.

[1] "On the Significance of the White Clays of the Ohio Region." American Geologist, July, 1892.

Re-elevation of the land. Between the deposition of this silt and the formation of the outer moraine of the later drift, the altitude appears to have become about as great as at the present, since, as shown below, the gravels deposited at that time along valleys leading away from the ice margin bear witness of vigorous drainage.

Outer moraine of the later drift. Since the position of this moraine is indicated on the accompanying map, it need not be outlined. It should, however, be stated that this moraine is overridden by a later one a few miles east of Hillsboro, Ohio, and has not been recognized in the eastern part of the State. The moraine consists of a ridge of drift one to two miles or more in width, standing, as a rule, but twenty to forty feet above the outer border plain. Its surface is gently undulating, there being but a few sharp knolls or ridges, such as characterize the surface of a later series of moraines described below. It is composed mainly of till, though gravel deposits are not infrequent, either in the low knolls or in beds or pockets incorporated in the body of the drift.

Striæ are numerous in the district immediately north of this moraine, and since the usual bearing is toward the moraine and not toward the glacial boundary, it seems evident that they were produced at the time of the later invasion. Some striæ near Cambridge City, Indiana, appear to be out of harmony with the ice-movement of the later invasion, and may, therefore, be older.

The older drift was but partially removed by this later invasion, and it is frequently encountered in wells and exposed in bluffs of streams. It is harder and dryer than the newer drift. In a few places, notably at Marshall and Martinsville, in Highland county, and in the vicinity of Wilmington, in Clinton county, a black soil is found at the base of the newer drift. I have seen it only at Wilmington, but Prof. Orton, in his report on Highland county, calls attention to its occurrence at Marshall, and I was told by well diggers of its occurrence in Martinsville. In Wilmington it is exposed in a railway cutting near the public school building, in the west part of the village. It consists

of black muck, several inches in thickness, overlain by till, and underlain by a yellowish sandy clay. The exposure only extends a foot or so beneath the muck, hence but little is known as to the character at this point of the underlying drift sheet. Dr. Welch, of Wilmington, has found pieces of coniferous wood imbedded in the soil in this and other exposures in that vicinity. He has preserved one piece which shows beaver cuttings. He has also discovered seeds of various plants imbedded in the muck, some of which now flourish only in higher latitudes. The contents of this muck-bed seem, therefore, to indicate an interglacial climate less genial than the present.

In his report on Montgomery county, Ohio, Professor Orton described a buried peat-bed exposed in the bluff of Twin creek, near Germantown. This peat contains the berries and fine twigs of cedar. At the time of Professor Orton's visit, in 1869, the peat was exposed for a distance of forty rods, and had a thickness of twelve to twenty feet. It was underlain by a bed of gravel. At the time of my visit, in 1889, its exposed thickness above the creek bed was about eight feet. It would seem, therefore, that the peat deposit has a somewhat lower altitude where now exposed than where Professor Orton saw it. Professor G. F. Wright, who has also seen the peat-bed, has suggested (Bull. U. S. Geol. Survey, No. 58, pp. 96-97) that it occupies a large kettle-hole, and that the higher portions of the peat-bed were near the rim. This peat-bed is overlain to a depth of 90 to 100 feet by a fresh-looking drift, mainly till, and evidently of the newer drift series. This locality is north of a later moraine than the one under discussion. It is not known whether the peat was accumulated during an interval of deglaciation between the formation of that moraine and the later one, or at an earlier time. The later interval seems to have been sufficiently protracted for the accumulation of this amount of peat.

Several wells in the east part of Wilmington have passed through a fossiliferous silt between the newer till and an older drift-sheet at a depth of about thirty feet. A few minute gasteropod shells obtained from this silt by Dr. Welch await specific

determination. None of them exceed one-sixth of an inch in diameter. Professor Chamberlin reports having observed a bed containing molluscan shells between the newer and older till-sheets at Greensburg, Indiana. (See Third Annual Report U. S. Geol. Survey, p. 333). Positive evidence is wanting as to whether these fossiliferous silts are of the same age as the silts which cover the district outside the moraine, but they appear to have about the same horizon. No fossils have been found in the silts outside the moraine. It seems not improbable, however, that if originally present their exposed situation is such that the fossils may have been dissolved and removed by leaching.

In the case of streams leading southward from this region of newer drift, careful discrimination is necessary to decide the age of terraces. The coarse, gravelly terraces of the Little Miami valley are referred to the stage when the outer moraine was formed. This valley carried a larger volume of water at that time than in later stages of glaciation, because it was more favorably situated for receiving glacial waters. The Great Miami valley was apparently flooded as much during later stages as at this time, and its gravels are largely of the age of the later moraines. The Little Miami gravels are made up, in large part, of coarse material as far down as the mouth of the stream, pebbles two to four inches in diameter being common. The coarseness of the material testifies to a fair gradient, presumably as great as the present altitude of the country affords. The gravels rise to a height of but fifty to one hundred feet above the present stream, and are near the bottom of the valley trench, for the uplands bordering this stream stand 300 feet or more above its bed. The flood stages, though characterized by a much more vigorous drainage than that which obtained while the silt was being deposited on the bordering uplands, did not reach by nearly 200 feet the limit reached by the silt-depositing waters —a fact which seems to be capable of explanation only on the assumption of great orographic movements.

Deglaciation interval in the later drift series. In his reconnaissance of Western Ohio, some ten years ago, Professor Chamber-

lin observed decisive evidences of the lapse of a considerable interval between the formation of a moraine lying east of Mad river, near Urbana and Springfield, and the moraines on either side of it, the moraine on the east being one of the later Scioto moraines, while that on the west is a Miami moraine. This older moraine proves to be the outer moraine of the Miami lobe (see map). While this moraine was being formed the Miami lobe occupied the Mad river drainage area, and the waters from the melting ice-lobe were forced toward the south into the Little Miami valley, passing just east of Springfield. The course is well defined, there being a gravel plain leading south along the east side of this moraine. The altitude of this gravel plain is much greater than that of the immediate bluffs of Mad river valley, but is lower than the water-shed between the Mad river and the Scioto river system, just east of it. It consequently presents somewhat the appearance of a broad irrigating ditch, following the face of a slope at a considerable altitude above the stream. When the ice had retreated from the Mad river basin the drainage of the high country to the east of Mad river soon opened channels directly across this gravel plain and the moraine west of it down to the trough in which the river flows. Similar channels were formed by streams leading down to Mad river from the elevated country west of its basin, and a broad valley was opened along the axis of the trough. When a fresh advance of ice occurred the Miami lobe came nearly down to the Mad river valley from the west and covered the upper portion of the western tributaries. Its moraine, in crossing the interglacial valleys, descends into them, but only partially fills some of them, thus repeating the phenomena of the outer moraine, in the Whitewater valley, as noted above. Similarly, the Scioto lobe trespassed on some of the eastern tributaries of Mad river, and its moraine partially fills the interglacial valleys. It should, perhaps, be stated that these interglacial valleys do not follow preglacial troughs, but instead, have bluffs standing as high as the interfluvial portions of the slopes of the basin. Their excavation began with the retreat of the ice-sheet from the outer Miami

moraine lying east of Mad river. It is difficult to determine the precise amount of excavation accomplished in this interval, since the portions of the valley lying beneath or within the later moraine are partially filled, while the portions lying outside the moraines afforded avenues for the escape of glacial waters, and were probably much enlarged thereby. It seems safe, however, to state that an amount of excavation took place that would require some thousands of years with a drainage system of the size of the present Mad river system, and with a gradient such as the region now affords. It may be added that in regions further west, if our correlations are correct, there are found evidences of the same deglaciation interval, but their discussion does not fall within the scope of this paper.

Main morainic system of later drift. The moraine just referred to (in whose re-entrant angle the Mad river basin lies) belongs to the system mapped and described by Professor Chamberlin, in the Third Annual Report of the U. S. Geol. Survey, as the "Terminal Moraine of the Second Glacial Epoch." As shown by Professor Chamberlin this moraine lies near the glacial boundary in eastern Ohio and north-western Pennsylvania, but farther west it falls short many miles of reaching the glacial boundary. It is a complex system, "constituting a belt rather than a single moraine," there being in places not less than four distinct members. Nearly everywhere in the state it presents a sharply indented surface, a feature which, as suggested by Professor Chamberlin, appears to indicate forceful or vigorous action of the ice-sheet. Its peculiarly sharp contours and their diagnostic characters make it the most conspicuous and distinctive morainic belt in the state. Other moraines, newer as well as older than this morainic system, assume in places the form of smooth ridges or have but gently undulating surface, and hence are less conspicuous features even where they have as great bulk as the individual members of this system. In western Ohio one of the members of this system (the second one of the group) carries on its surface large numbers of crystalline bowlders of Canadian derivation and the remaining members are liberally

supplied. In this respect this morainic system contrasts with all other moraines of Ohio, and especially with the later moraines, there being but few bowlders on their surfaces. In eastern Ohio bowlders are a less conspicuous though not a rare feature. The cause of this unusual abundance of bowlders is an interesting problem and one perhaps not easily solved. It has been suggested by some one, I think it was Mr. McGee, that an unusual abundance of bowlders on the later drift sheets may be an indication that the ice invasion which brought them in was preceded by a long deglaciation interval in the gathering ground, and that the Canadian highlands were scoured afresh after the lapse of sufficient time for ledges to have been seamed and broken under atmospheric influence. The suggestion seems worthy of careful consideration.

The drainage from the ice-sheet was especially vigorous at this time throughout the entire width of the state and as far to the east and west as this morainic system has been identified. The altitude could not well have been less than at present, and may have been somewhat greater.

The later moraines. Between this morainic system and the western end of Lake Erie six more or less distinct moraines occur, which were probably formed in comparatively rapid succession. They each consist usually of a broad ridge one or two miles or more in width, and twenty-five to fifty feet in height. They are each sufficiently bulky to have determined to a large extent the courses of the main drainage lines of northern Ohio (see map) and yet they seldom present a sharply indented or conspicuously broken surface. The overwash aprons and terraces connected with them indicate less rapid discharge of waters than from the earlier moraines, and that too in certain parts of the belts where conditions were very favorable for rapid escape of waters as in the north part of the Scioto basin. It is thought from this feature as well as from the aspect of the morainic ridges themselves, that the ice-sheet had less vigor than when forming earlier moraines. That there was a decrease in altitude seems also highly probable. As noted above, surface bowlders

are of comparatively rare occurrence, being apparently no more plentiful than in the body of the drift. The aspect of this group of moraines is so very different from that of the group which lies outside it, that it is thought not improbable that they are the product of a distinct invasion. No decisive evidence of a long deglaciation interval separating the two groups has, however, been discovered.

Summary. From the facts above presented the following stages of the glacial period seem sustained:

1. A glacial stage during which the ice-sheet extended farther south in western Ohio than in any later stage. This stage will need subdivision in case a buried soil horizon in the midst of its deposits be well substantiated.

2. A long stage of deglaciation marked by development of soil and by attendant oxidation, leaching and erosion of the drift sheet.

3. A stage of silt deposition during which the highest points in south-western Ohio apparently became covered at flood stages. From evidence gathered elsewhere it seems probable that the silt deposition accompanied a glacial stage whose deposits are concealed in this region by later drift sheets.

4. A glacial stage, during which the outermost well-defined frontal moraine was formed. The drift of this stage is concealed in eastern Ohio by the later moraines. Preceding this stage is an interval during which the valleys became opened again to such depth that the main streams, at the time of this later ice invasion, flowed at levels 200 feet or more below the level of the upland silt.

5. A stage of deglaciation of considerable length as indicated by valley excavation.

6. A glacial stage characterized by sharply indented morainic ridges, thought to indicate vigorous action. The ice-sheet reached about to the glacial boundary in eastern Ohio, but fell short many miles of reaching the boundary farther west.

7. A glacial stage characterized by morainic ridges of smooth contour. This stage embraces the final disappearance of

the ice-sheet from Ohio. A deglaciation interval is believed to have preceded this stage, but as yet, decisive evidence in support of this view is not obtained.

We may now profitably review what is known concerning the altitude in each stage:

1. During the earliest advance little of value is known in this region. The scarcity, if not absence, of coarse overwash material seems to indicate feeble drainage and consequent low altitude. It is true that the Split rock and Middle creek conglomerate indicate powerful water action, but if formed as they appear to have been beneath the ice-sheet, they show little as to the altitude of the land.

2. During the period of deglaciation following the deposition of the earliest drift there appear, from the character of the changes effected, to have been fair drainage conditions. We may presume, therefore, that the altitude was not much lower than the present altitude of the region (800–1000 feet A. T.).

3. During the period of silt deposition there can be little doubt that the region stood several hundred feet lower than now.

4. During the formation of the outer moraine of the later drift there were apparently as good drainage conditions as are now afforded in the western Ohio region.

5. During the succeeding deglaciation interval the erosion effected indicates a fair altitude.

6. During the formation of the main morainic system the maximum of elevation was probably reached, there being an especially vigorous drainage at that time, not only in Ohio, but as far to the west as the moraine has been correlated.

7. During the formation of the later moraines there seems to have been a return to low altitude, and still later the Champlain submergence of the coast and St. Lawrence occurred. It is important to note that the Champlain submergence is separated from the submergence which produced the silts of southern Ohio by the periods of high altitude just mentioned, a succession of

periods during which all the Ohio moraines, no less than twelve in number, were being formed.

The decision as to the relative length of the intervals of deglaciation is obviously dependent upon data gathered from the entire glacial field, and should not be rendered in the light of what can be gathered from this limited region.

FRANK LEVERETT.

TRACES OF GLACIAL MAN IN OHIO.

TRENTON and the Delaware Valley no longer have exclusive claims to reputed evidences of glacial man. For a number of years reports have come from the West of finds of implements in ice-age drift. Miss Babbitt in Minnesota, Cresson in Indiana and Metz and Mills in Ohio, have in turn announced the discovery of specimens of these rare and precious mementos of antiquity. I have already, in papers published in THE JOURNAL OF GEOLOGY and in the *American Geologist*, raised questions as to the proper interpretation of the finds in Trenton and at Little Falls, Minnesota. A brief study of the Ohio finds may now be undertaken with a view of presenting and weighing such doubts as may have arisen with respect to the value of the evidence furnished by them. I have endeavored in this, as in the other cases, to keep well within the bounds of legitimate criticism, desiring to allow all that can be justly claimed for the evidence presented in support of the theory of a glacial paleolithic man in America. In dealing with this subject, however, I have found it necessary to keep in mind the fact that the evidence to be considered has been collected and presented by advocates of the paleolithic theory who have welcomed finds without critical scrutiny, and have reached and presented conclusions as much because they were in the line of the expected and desired, as because they were actually susceptible of demonstration. The advocates of the theory have naturally taken every opportunity to emphasize the importance of the evidence collected as viewed from their own standpoint. To insure correct final judgment it is necessary that other points of view be taken and that the evidence be subjected to every possible test. I shall confine myself to fields in which I have made personal and most careful observations. I do not desire to secure the acceptance as final of any particular view with respect to the history of early man in America. I am not intro-

ducing or advocating a theory but attempting to insure the non-acceptance of any theory, howsoever plausible, that is not supported by conclusive proofs. Others have undertaken to show how much proof Ohio has furnished in support of a particular hypothesis; they cannot now object to my attempting to show how insignificant this proof really is.

At the meeting of the American Association for the Advancement of Science in Washington, in 1891, much attention was paid to glacial geology, and one paper by Mr. Frank Leverett, of the Geological Survey, treated of the gravels of Loveland, Ohio, and of the finds of implements in them by Dr. C. L. Metz. Mr. Leverett was then about to return to Ohio and I resolved to accompany him to the Little Miami Valley with a view of making a brief preliminary study of the gravels and their contents. A week later Dr. Metz joined us at Loveland, and we proceeded at once to the great gravel pits just west of the village. Gravel was then being taken by the Baltimore & Ohio Railway Company from the south side of the road, two hundred yards beyond the bridge, but the old pit is a little farther on and on the north side of the road, the excavation running into the high terrace from the track at an oblique angle. The excavation is upward of two hundred yards long, and is from two hundred to three hundred feet wide, and has an average depth of perhaps twenty-five feet. The west wall had not been worked recently, and was reduced by erosion to a steep slope covered with vegetation. The curved wall of the east side was thirty or more feet high and very steep, affording an excellent exposure of the gravels; these consisted of very coarse material laid down in heavy irregular beds. At least one-fourth of the mass consisted of sub-angular or but imperfectly rounded slabs and flattish masses of limestone, which lay flat or with a slight inclination toward the river. The larger slabs, which were often as much as two feet or more across, projected like steps or shelves from the wall. The remainder of the deposit consisted of smaller rounded masses and bits of limestone; of masses, bowlders and pebbles of granitic rock constituting perhaps one-

twentieth of the deposit, and of gravel, sand and calcareous powder.

There were, in places, indications of rude lenticular bedding of these materials with a pretty uniform general inclination toward the channel of the river. The appearance of newness exhibited by these deposits was wonderful; the surfaces of the stones were smooth and clean, and many of the interspaces were open as if formed but yesterday. A closer examination showed, however, that this appearance of newness was partly due to the fact that the waters charged with calcareous matter penetrated the superficial beds, partially setting the constituent parts and in a measure sealing the apertures, thus preventing the complete settling and filling that otherwise would have taken place. The constitution and conditions were pretty uniform throughout the section, save at the top where there was a deposit from two to four feet deep of ferruginous sandy loam, containing some fragments, pebbles and bowlders of several varieties of stone.

After three visits, and the most careful but entirely fruitless search for relics of art from bottom to top of the gravel walls, I found myself wondering whether there had not been some mistake, whether the objects found were really tools, or whether the collector had not mistaken materials descended from the surface deposits for gravel in place. It is unfortunate that the statements of collectors in such cases, correct or incorrect, cannot readily be subjected to competent tests of verity; we must be content with hedging them about with all available restrictions in the way of negative evidence.

Having, during the first visit, examined the site at some length, we proceeded to the office of Dr. Metz, in Madisonville, and were shown two objects obtained from the pit at a depth of about twenty-five feet beneath the surface. The smaller of these, a dark flattish piece of cherty, slightly water-worn stone, was rudely flaked along one edge, but the evidence of design was not at all convincing, and it seems useless to place the specimen in evidence. The other object was apparently a work of art, exhibiting decided indications of design. It was found in

the main gravel pit about twenty-five feet from the surface, by Dr. Metz, who expresses his full belief that it was in place in the gravels when found. A third slightly flaked stone from the same locality and position had been forwarded to the Peabody Museum at Cambridge. On examining this specimen at a subsequent date I found that it has no features that can with certainty be described as artificial.

It is not from a desire to discredit the observations of Dr. Metz, who is a most reputable and more than usually capable observer, that I raise the question of the verity of these finds. It is essential, in a case where so much depends on the finding of a single specimen, that every observation relating to it should be placed upon record in such a way that, in the future, judgments as to the value of the evidence may not be based entirely upon the testimony of a single observer whose acquirements may be restricted or whose preconceived notions may give a very marked bias to his observations and deductions.

Referring to the Loveland site, it may be remarked in the first place that it seems improbable that man would have occupied an area overrun by torrents capable of transporting, and transporting almost exclusively, the coarse materials forming these deposits, and the chances of the preservation of artificial features of specimens brought by floods from the valley above are extremely slight.[1] Of course, if man existed here during the glacial period, he may have sought the raw material for his rude arts on the banks of this stream during the periods of of low water and may have thus left the refuse of his shaping operations at almost any point; but a single specimen cannot, considering possible errors of observation, be regarded as sufficient for the establishment of such a conclusion.

In the second place, I may mention the fact that on carefully examining the Loveland specimen, I found it partly covered with dark, well-compacted earth, resembling the soil of the surface of

[1] The edge of the continental ice sheet was, according to Mr. Leverett, only about eight miles distant when these gravels were formed, which makes the probability of finding implements here still slighter.

the terrace, rather than the light-colored, fine-grained calcareous powder characterizing the matrix, such as there is, of the gravel deposits. It seems to me that there is in this observation, made also by Mr. Leverett, and still subject to verification if the specimen has not yet been cleaned, sufficient ground for raising the question as to whether it is possible that Dr. Metz could have mistaken a surface mass, descended into the pit from above, for gravel in place. Dr. Metz, or any other observer not a professional student of geologic phenomena, especially of talus phenomena, involving materials subject to resetting after degradation, or to sliding *en masse*, could readily be excused for making a mistake of this kind. Lest this suspicion of error should seem unfounded or uncalled for, I have prepared two sections, Figs. 1 and 2, which illustrate some of the many dangers besetting the way of gravel searchers. In Fig. 1, an ordinary profile, resulting from the removal of gravels for railroad ballast, is shown. Deserted by the workmen for a day or a week, objects from the surface deposits, *A*, may have fallen into the pit resting at *B*. The sliding of the mass, *a b*, might cover them to the depth of several feet, *C*, Fig. 2, and the effects of disturbance upon the surface are soon obscured or obliterated by weathering. Suppose now that Dr. Metz, or any one else, should appear upon the scene as the fallen mass is removed and penetrated by workmen, and should witness the uncovering of art forms at *D*, twenty-five feet beneath the surface of the terrace. It is vain to hold that there is no danger of mistake in such a case; the chances of error are really very great, and a little slip like this in observation would falsify the chronology of human history in this valley to the extent of some thousands of years.

It may be remarked that the terraces of the Little Miami were for a long period occupied by mound-building tribes whose implements and refuse of manufacture are scattered everywhere, and it is entirely within the range of possibility that such a partially worked specimen as this should have been left by them in the surface loams on the site of this pit at Loveland.

As to the nature of the object itself, a number of questions

may be raised, and we are justified in making all possible inquiries. It is a pick-like object, some six inches long, and perhaps two inches thick toward the larger end. The head is rounded, as if intended to fit the hand, and there is even an appearance, deceptive, no doubt, as will appear further on, of abrasion by use. The sides are neatly flaked, the apparent result of blows by a hammer, many of which seem to have served only to batter the edges, while others appear to have removed a series of flakes extending along the shaft from the head to near the point. The smaller end of the object is worthy of especial notice; the point, which probably was originally sharply pyramidal, has been removed by an oblique fracture, leaving a clean, unworn surface. A portion of the surface adjacent to the truncated point has not been shaped by flaking, but retains the original minutely granular weathered surface, indicating that the stone before flaking or remodeling was already pointed. The object was therefore not used after the breaking of the point, as the unworn fracture shows, and the presence of the unaltered original surface adjacent to the present point would seem to prove that it never was subjected to use. The material appears to be a fine-grained, light-colored limestone, having a conchoidal fracture. It is soft and brittle, and is not likely to have been employed in making tools, and especially pick-like tools. This observation leads to an inquiry as to whether it is possible that the flaking could have been the result of natural agencies, such, for instance, as the crushing and abrading forces exerted by moving ice. Could a pointed bit or mass of brittle limestone have been so squeezed between moving impinging rocks as to remove these flakes and to produce the battered and rounded effect seen upon the edges and head, respectively, of this object without affecting the point, save to break it, and without breaking the shaft elsewhere? That natural forces do occasionally produce forms resembling those of art is well known, and that archæologists have at times been rash in accepting such as artificial cannot be denied.

To more fully inform myself upon this topic I made careful examinations of the contents of the moraine from which por-

tions, at least, of these gravels descended. I was somewhat surprised with the results, which proved so interesting and suggestive that they may well be referred to in this place. In a railroad cut recently made through morainal deposits near South Lebanon, about eight miles north of Loveland, I found numerous pieces of this brittle limestone, varying from minute bits to masses a foot or more in greatest dimension, showing traces of fracture and flaking resembling somewhat closely those of the implement or object found by Dr. Metz at Loveland. Indeed, some of these specimens are so well flaked that I would, under ordinary circumstances, not hesitate to call them artificial. In fact, all may be artificial, although the shapes are often eccentric, and the size, in cases, is greater than in any known flaked tool. It is a significant fact that nearly all the stones found in the deposit are covered with glacial striæ, and some of the conchoidal faces of the implement-like objects are scratched, through movements of the ice. It is true that man may have lived or hunted on or near the ice, and his tools or the refuse from their manufacture may have been taken up by the ice, passing afterwards into the moraine; but that they should enter the ice in numbers, and so become striated through its movements, is highly improbable. The Loveland specimen has, however, a more decidedly artificial character than any of these, and were its inclusion in the gravels fully verified, and were it not alone and practically unsupported by other finds, it could well be accepted as important evidence of glacial occupation by a stone-flaking people.

Besides the Loveland finds, Dr. Metz obtained a specimen of rudely flaked black chert from a cistern which he was sinking in Madisonville, Ohio. It was found at the surface of, or slightly imbedded in, gravel beneath a bed of silt eight feet thick.[1] Dr. Metz is a careful observer, and it is hard to believe that he would have permitted himself to be deceived although all must

[1] Putnam, F. W. Proc. Boston Soc. Nat. Hist., Vol. XXIII, p. 242.

Wright, G. F. Ice Age, pp. 530-532.

Leverett, Frank. Am. Geologist, March 1893, p. 187. According to Mr. Leverett it is not certain that these silts belong to the ice age, and if not, the find is no evidence of glacial man, whatever else it may signify.

admit the possibility of such deception. I have examined the specimen, now in the Peabody Museum, and find it to be identical in every essential feature with typical rejects of the modern blade-maker, lacking the least indication of specialization. It is not safe to call it an implement, no matter what its age, and to present it as evidence of paleolithic culture is little short of folly.

The discovery of a number of ancient hearths on the banks of Little Miami river was announced several years ago, and may be referred to in this place, since they were associated with deposits of ancient-appearing gravel. Professor Putnam gives the following information in regard to them: An exploring party "discovered five ancient hearths half a mile down the river from the Turner group of earthworks. These hearths were exposed by the river cutting away its bank. The lowest of the five . . . is thirteen feet below the surface of the bottom land, and rests upon a layer of gravel seven inches thick, upon which rest ten feet of alluvial deposit. This is by far the lowest and most ancient of the many hearths which from time to time have been exposed by the action of the river, as first noticed several years ago by Dr. C. L. Metz, who has examined a number of these ancient fire-places, and on one found fragments of pottery, which he sent to the Museum last year. These hearths are made of small boulders, in each case covering an area of several square feet. These stones are burnt, and many are splintered by heat. Upon the stones forming this oldest hearth was a considerable quantity of ashes and charcoal, but no other evidence of the work of man. These hearths furnish evidence of the occupation of the bottom land at different intervals during the formation of this deep deposit, filling the valley for miles in extent. That in this lowest hearth we have a considerable antiquity is self-evident; but how long after the formation of the glacial moraine, from which the gravel overlying it was derived, will only be determined by a careful study of the geology of the whole valley.[1]

[1] Putnam, F. W., 23d and 24th Annual Reports of Peabody Museum, p. 92.

In 1891 I visited this site with Mr. Frank Leverett. Traces of the fire-marked stones were found, but the waters had removed the hearths previously observed. A critical examination of the sedimentary deposits leaves the impression that they are quite modern. The upper surface is but little above the present flood plain, and has the appearance of a modern alluvial deposit of black, loamy earth, including thin irregular layers of fine gravels. I see no reason, considering the facility of mutation characterizing such deposits, why the hearths may not have belonged to the occupants of the site of the noted Turner group of mounds near by. It is seen from Professor Putnam's report that there were many hearths in and beneath these works. "An examination was also made of the surrounding embankment of the work, and much to our surprise portions of it were found to cover large areas of burnt stones. Several of these old fireplaces were explored inch by inch with the trowel, and in the ashes and among the charcoal were found numerous pieces of the bones of various animals, many potsherds, flint chips, broken and perfect implements, ornaments of several kinds, pieces of mica, etc., all similar to what has been found in previous years at other places in this interesting group of earthworks."[1] It may, I believe, be taken for granted that these hearths, notwithstanding their intimate relations with deposits of gravel, will never form any part of the evidence arrayed in support of an ice-age man or a paleolithic culture.

Another discovery, to which much attention has been given on account of its supposed bearing upon the paleolithic question, was made in 1889. Mr. W. C. Mills, of Newcomerstown, Tuscarawas county, Ohio, found a single specimen of chipped flint in an exposure of glacial gravel in that place. The specimen fell into the hands of Professor G. F. Wright, by whom it has been widely exhibited and published. A cut of it appeared in his "Man and the Glacial Period," from which work a brief extract may be given in this place. He states that Mr. Mills found this "finely shaped flint implement sixteen feet below the surface of the

[1]Putnam, F. W., 23d and 24th Annual Reports Peabody Museum, p. 94.

terrace of glacial gravel which lines the margin of the Tuscarawas valley. Mr. Mills was not aware of the importance of this discovery until meeting with me some months later, when he described the situation to me, and soon after sent the implement for examination. In company with Judge C. C. Baldwin, President of the Western Reserve Historical Society, and several others, a visit was made to Mr. Mills, and we carefully examined the gravel-pit in which the implement occurred, and collected evidence which was abundant to corroborate all his statements. The implement in question is made from a peculiar flint which is found in the Lower Mercer limestone, of which there are outcrops a few miles distant; and it resembles in so many ways the typical implements found by Boucher de Perthes, at Abbeville, that, except for the difference in the material from which it is made, it would be impossible to distinguish it from them. The similarity of pattern is too minute to have originated except from imitation."[1]

In another place Dr. Wright gives a statement of Mr. Mills in regard to the specimen, from which I quote the following additional details: "While examining the different strata of the gravel, I found the specimen that you have before you fifteen feet from the surface of the terrace. The bank was almost perpendicular at this time, exposing a front of about twenty feet. The small part of the bank was in place in the side of the terrace, until I struck it with my walking-cane, when a space of about six feet in length by two feet in height tumbled down, exposing to view the specimen. At first I recognized the peculiar shape and glossy appearance of the specimen, such as were characteristic of paleolithic specimens described to me by Professor Edward Orton, while I was a student at the Ohio State University."[2] Mr. Mills has, I believe, published nothing save through Professor Wright, and we must therefore take the above as the authoritative statements of the finding. A re-statement embodying additional minor details and placing the evidence fully and

[1] Wright, G. F. "Man and the Glacial Period," p. 251.

[2] Wright, G. F. Report of Western Reserve Historical Society, Dec. 12, 1890.

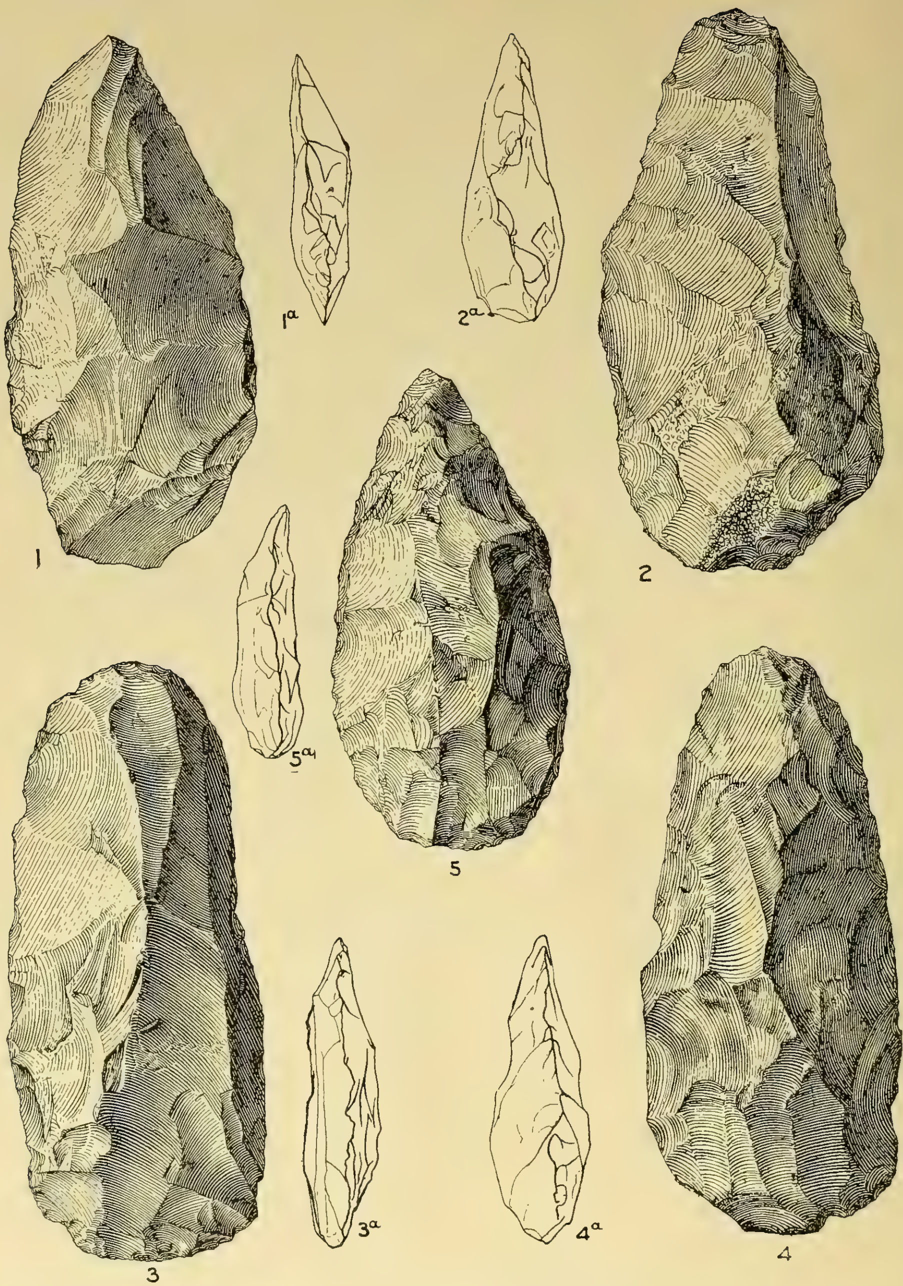


Plate illustrating the Newcomerstown "paleolith," copied with all possible care from the cut in "Man and the Glacial Period," and four ordinary rejects of the blade-maker, the latter obtained in three cases from modern flint shops in the same region, and in the fourth case directly traceable to the same shops. The separation of the "implement" of glacial age and paleolithic type from the modern rejects is left to the reader. Three-fourths actual size; the profiles on a still smaller scale.

finally upon record, an excellent thing to do, appeared in *Science* for February 3, 1893.

The question may now be raised as to the value to be attached to this find, since the observation is one upon which much is made to depend. In September, 1892, I visited Newcomerstown and examined the site of the discovery of this interesting object, which is shown in the accompanying plate. The town is built along the margin and on the slopes of a glacial terrace, formed about the end of a spur of the hills which projects into the valley on the north side of the Tuscarawas. The exposures of the gravels in the railway ballast pit are excellent, showing them to be ordinary irregularly bedded deposits of sand and gravel. It is a sufficiently promising place for the recovery of such implements or objects as the gravels may happen to contain. The formations are very loosely bedded, and it takes but a short time after the desertion of the site by workmen, especially if the weather is wet, to cover the exposures with talus. Large masses are liable to fall, carrying with them all objects resting upon and near the surface. A collector not on his guard, or not appreciating the nature or significance of finds, might readily, when afterwards questioned about the matter, give a faulty diagnosis of the conditions of discovery. The case in hand is one in which double assurance of verity is called for, yet it is one in which uncertainty resulting from the lack of experience and possible, I may say probable, carelessness of the collector is augmented by the treachery of the gravels. This uncertainty is again emphasized by the discovery, made at the time of my visit, that this terrace is probably an old Indian village site, and certainly a shop site where flint was flaked, many rejects and flakes occurring upon the very brink of the pit. Of course I found no duplicate of the specimen in question, for duplicates are *raræ aves;* but I saw enough to convince me of the danger of hastily and unqualifiedly making use of the observation made by Mr. Mills, especially since the material of which this object is made occurs in the neighborhood, and must have been used by the Indians inhabiting this site.

There is no doubt that this specimen suggests, perhaps more decidedly than any other American so-called gravel implement thus far collected, a resemblance to one of the well-known European types of implements. This is noted by Professor Wright, and may be regarded by many as a point worthy of attention. We must, however, look with extreme caution upon deductions drawn from or depending upon analogies of form. Close analogies of form between Indian rejects and some varieties of European paleolithic objects are too common to permit the attachment of much value to this feature of this or any other similar find. The remark of Professor Wright quoted above, that "the similarity of pattern is too minute to have originated except from imitation," is rather a novel statement, since no specimen of its type has been reported from the American gravels, and the Newcomerstown man could hardly have been familiar with European forms. The only available models would appear to be the Indian rejects of the valley of the Tuscarawas.

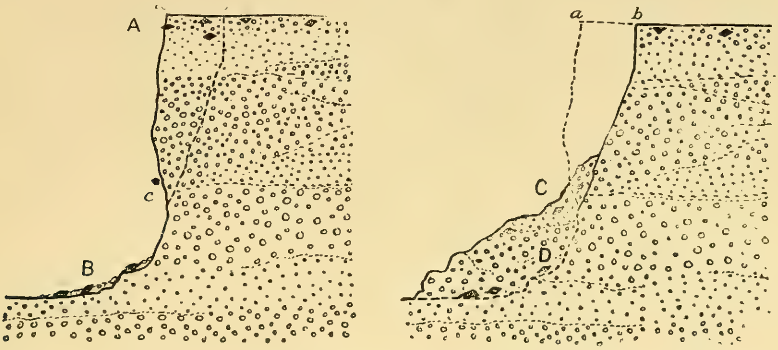
As to the surface polish, that is a common feature of the Ohio flints, and I have before me during this writing a tray of quarry rejects that have the same glazed effect. This is a characteristic of the stone, and has no bearing upon questions of age or use or culture, and must be considered as without significance in these connections.

Professor Wright is entirely satisfied with the results of his efforts to corroborate the statements of the collector. He has examined and reëxamined Mr. Mills, receiving every assurance of the verity of the find, but after all he really secures no additional assurance and can receive no fully satisfactory assurance that Mr. Mills was not in error. Professor Wright has visited and photographed the site and will speedily prepare a plate for publication,[1] for just what purpose, however, it is rather hard to see, since the nature of the gravels is not disputed, and a volume of photographs will not give additional weight to the proofs. A photograph made of the tree after the bird has flown will not help in determining the bird. No more will observations on Mr.

[1] Wright, G. F., Science, February 3, 1893.

Mills' moral character, his education or business reputation, diminish the danger of error. The specimen may not have been found in place notwithstanding all possible verification, and it may be a reject notwithstanding its resemblance to foreign types, and Professor Wright may be wrong in urging his conclusions upon the public, notwithstanding his painstaking efforts to secure all possible affirmative testimony.

It is nowhere stated that Mr. Mills actually picked the specimen out of the gravels; it was probably loose when he dis-



Figs. 1 and 2. Sections of wall of gravel-pit showing redistribution of surface objects by sliding masses. The dark figures represent objects of art.

covered it, but even if he could say that it was fixed in the gravel mass, the necessity of questioning the find would still exist. All the authentication Professor Wright can possibly secure will not enable him to determine whether Mr. Mills struck with his walking stick a small mass of the gravel in place at a depth of sixteen feet, or whether he was dealing with a mass which had slid with its inclusions of modern relics from the surface to a depth of sixteen feet, as indicated at C, Fig. 2. The object *may have been* in place, but can we afford to decide momentous questions upon the evidence furnished by a single specimen obtained under the conditions existing in this case, and by a collector who for months after the finding "was not aware of the importance" of the discovery?

At Warsaw, in Coshocton county, fifty miles west of Newcomerstown I visited an exposure of gravels in a railway cutting, the conditions being almost identical with those at Newcomerstown. The terrace, as in the other case, has been occupied by Indian flint workers, and being in the proximity of extensive flint quarries, there is much refuse of manufacture. I gathered a peck of turtle-backs and rude objects of paleolithic types from the level ground above, and in the wall of the gravel pit found several pieces, descended from the surface, that would be freely admitted into the paleolithic family by its sponsors. Work in the excavation had ceased several months before, and the face of the bluff, nearly thirty feet high and two hundred yards long, was well veneered more or less deeply with talus deposits, through which in places and especially near the top, the normal gravels could be seen. The redistributed deposits along the base of the steep slope were well reset, and from these I obtained a number of flaked flints; several of which were firmly imbedded, and two of them were removed from the gravel with some difficulty and with the aid of a pick, one twenty-five and the other twenty-seven feet beneath the surface of the terrace. The latter specimen is shown in the accompanying plate.

In studying this section at Warsaw I was led to realize the folly of hastily using inexpert evidence regarding the finding of relics of art in gravels. In a case like this even the experienced scientific observer, whose attention had not been definitely called to the nature and far reaching significance of such finds, might from a casual observation have recorded the recovery of one or more of these objects from the gravels. The danger would be greatly increased if the observer were only a relic hunter, or if he were convinced that the gravels at any depth might be expected to contain such objects. These specimens were in the gravels, firmly imbedded, and to all appearances this particular portion of the deposit was in a normal condition. Any one could here have dislodged a portion of the mass with his walking-stick, with fair prospect of finding a flaked stone of paleolithic type. I doubt very much if we are justified in using the casual obser-

vation of an inexpert collector at all in questions where there is no other well-established body of evidence with which to associate it. The function of such data does not extend legitimately beyond the confirming of testimony already well verified.

I present in the accompanying plate examples of the finds from the gravel talus and from the shops above. They correspond very closely in material and appearance with the Newcomerstown specimen, as will be apparent from an examination of the plate. The figures are presented without identification in order that the student may, by an effort to distinguish them, convince himself of the similarity of the supposed paleolith to the quarry-shop rejects of the region. I am not satisfied with the drawing of the former specimen which is a copy, the best that could be made, of the cut published in "Man and the Glacial Period." I desired to have a new drawing direct from the specimens, but a request looking to that end, made to Professor Wright, met with no response.

The four quarry-shop failures here shown are not rare finds with unusually implement-like features. They are everyday rejects, and four hundred could be presented as readily as four.

Summing up the evidence of gravel man in Ohio, assembling all of the finds of several earnest workers these many years—the fulfillment of Professor Wright's prophecy—we have to consider three specimens only. The finding of these objects seems ordinarily well attested, and there is not the least hint of deception or partial withholding of details of discovery. The specimen found by Dr. Metz in his cistern was eight feet deep, and on, or in, the surface of the gravel bed beneath eight feet of silt that may or may not be glacial. Eight feet is not a great depth, however, and we are justified, so long as the specimen stands alone, in expressing our fears that it might, through some unsuspected disturbance of the soil, artificial or natural, have been introduced or covered up to this depth at some date in the long period separating the ice age from the present. A number of agencies known to disturb the soil to considerable depths, are referred to in my paper on early man in Minnesota, in the April

number of *The American Geologist*, and Mr. Frank Leverett, in the March number of that journal, dwells at some length upon this subject. In response to an inquiry, I received the following note from Dr. C. Hart Merriam, the naturalist, on the burrowing of native animals:

"In reply to your inquiry respecting the depth to which our burrowing mammals penetrate, I regret to say that precise information on the subject is somewhat meager. A number of species, such as our woodchucks or marmots, skunks, foxes, coyotes, badgers and prairie dogs live in burrows of greater or less depth which they construct for themselves. In a few instances these burrows are known to extend to a depth of eight feet or more. One of the gophers is said to dig a spiral well fifteen feet deep. Badgers and prairie dogs are notorious diggers, making vast numbers of holes and bringing up immense quantities of material from unknown depths. Their burrows, moreover, are usually very steep, so that a stone or other object falling into one would descend to a considerable distance before being intercepted. Badgers and coyotes make very large holes, though small in comparison with those of the large wolf, which was formerly abundant throughout the Mississippi Valley; the burrows of the latter animal are of sufficient size to readily admit the body of a small boy."

The Loveland specimen was recovered at a great depth beneath the surface but we are bound to raise the queries, Is it an implement? Was it in place; and what is the meaning of the dark soil found on its surface? Of the Newcomerstown specimen it may be said that the collector had little knowledge of the nature of the gravels and of the treacherous character of talus deposits, or of the importance or peculiar bearing of the find. There is, therefore, a most serious possibility of error. There is a decided chance that errors of observation may have crept in in all the cases.

And what is the story of the specimens themselves? The Madisonville object is to all appearances an ordinary reject of the flint-blade maker. It can be practically duplicated upon

almost any quarry-shop site. The pick-like object from Loveland is somewhat unique, and thus has a certain interest of its own, independent of the manner of its finding. At best, however, it was probably not a finished implement at all and there is strong evidence that it has never been used. It may not have more than a remote resemblance to any tool ever employed by the occupants of the valley. The Newcomerstown object appears to have a marked resemblance to certain foreign implements, but the Tuscarawas valley flint-shops furnish many other specimens whose analogies are nearly if not quite as close.

These specimens constitute the Ohio evidence. There is nothing more, for it would be a great mistake to present surface finds as "paleoliths" or as gravel art, no matter how close their resemblance to these or to European forms. It is safest to assign all to the historic Indian save those obtained and proved to have been obtained from the gravels in place.

These three specimens furnish the most satisfactory proofs, so far collected, that a glacial, paleolithic man inhabited the Ohio valley, and upon the evidence of these three slightly shaped stones, obtained from isolated localities, it has been proposed to carry the history of man back some thousands of years farther than can be done by any other means yet discovered.

No careful student will venture to say that the evidence furnished by the three specimens is satisfactory and conclusive. The finds are not demonstrably implements but have the characteristics rather of rejects of manufacture. Their employment as evidence of a *paleolithic stage of culture* serves only to emphasize the utter inadequacy of the available proofs on that point.

Considering the meagre and unsafe nature of these proofs, there seems little doubt that a *glacial man* for the Ohio valley has been somewhat prematurely announced and unduly paraded.

W. H. Holmes.

THE VOLCANIC ROCKS OF THE ANDES.

THROUGH the excellent work of Dr. Richard Küch,[1] who has recently published the results of his investigation of the rocks collected by Reiss and Stübel in Colombia, we are put in possession of some important conclusions regarding the character of all the volcanic lavas of the South American Andes. Most of these conclusions are pointed out by Dr. Küch in the work cited; to these the present writer wishes to add a few not heretofore noted.

In order to appreciate the value of Küch's work, it should be observed that it was carried on upon the very extensive material collected by Reiss and Stübel during a prolonged exploration of the high mountainous regions of South America, in which they visited Colombia, Ecuador, Bolivia, Peru and Chili and brought away with them 18,000 specimens. In some places as many as 800 were collected, in others much fewer; for, as Reiss observes in the introduction to the volume upon Colombia, many of the mountains are well nigh inaccessible, their bases being covered with dense forest, and their summits hidden beneath snow and glaciers, and shrouded with clouds the greater part of the year. This is equally true of the Cordilleras farther south, so that the exploration of the region is attended with great difficulties. And while it is not claimed that the collections are complete, they must certainly be taken as representatives of the whole of the Andes.

The volcanoes of Colombia chiefly occur along the crest of the central range, rising above crystalline schists, and eruptive masses in the Cretaceous formation, whose upturned strata compose the ranges east and west of the central Cordillera. Heretofore, with few exceptions, the volcanic rocks examined have

[1] W. Reiss and A. Stübel: Reisen in Süd-Amerika. Geologische Studien in der Republik Colombia, I. Petrographie. 1. Die Vulkanischen Gesteine bearbeitet von Richard Küch. Berlin, 1892.

been from the Andes south of the equator. In the present instance our knowledge of them is extended to the most northern end of the great Cordilleran system.

A critical review of all previous work upon the lavas of the Andes, and its comparison with that by himself on the lavas of Colombia, and with a preliminary study of the collections by Reiss and Stübel from Ecuador, led Küch to the conclusion that essentially the same petrographical relations exist at all the volcanoes of the Andes.

With few exceptions all of these recent volcanic lavas of which we have any knowledge, are andesites and dacites, that is, rocks whose essential constituents are soda-lime-feldspar and one or more of the minerals: pyroxene, hornblende and biotite, with which is associated quartz, in the case of dacite. Recent eruptive rocks whose mineral composition falls outside of this group appear to be of rare occurrence, and are rocks closely related to andesite and dacite in composition, namely: quartz-trachyte or rhyolite on the one hand, and basalt on the other. In two instances rocks described as trachyte and quartz-trachyte by Stelzner are shown by Küch to be more properly dacite.

The known occurrences of true basalt are few, the most basic rocks being more closely related to pyroxene-andesite than to basalt, according to Küch's interpretation. Dacite, though seldom mentioned by previous investigators, is of very frequent occurrence judging from the collections by Reiss and Stübel.

The study of such abundant material naturally led Küch to first treat the lavas of Colombia as one general group of intimately connected varieties, without reference to their geographical distribution, for it became evident, as he remarks, that neither a single rock, nor a specially abundant development of any one kind, nor the association of a certain number of different rocks could be considered characteristic of any particular volcano. The same rocks with like multiplicity of development, and the same associations of rocks, repeat themselves in different localities in such a manner that what may seem to be the prevailing or the subordinate varieties in one place are more likely to appear such

because of the greater or less completeness of the material collected, than by reason of their actual scarcity or abundance in nature.

The chief feature of the report consists in the systematic description of the lavas of Colombia based upon their microscopical investigation in conjunction with their chemical analysis. The second part of the report is devoted to a description of the rocks in connection with their geographical distribution. It is to be regretted that the geological relations of the rocks with one another are not furnished at the same time.

The rocks are first discussed from a mineralogical standpoint, their mineral composition and structure being taken as the basis of classification within the general group of extrusive igneous rocks, to which they all belong. They are all embraced within the families of andesite and dacite, as defined by Rosenbusch. They present a chemical series grading from rocks relatively poor in silica and rich in lime and magnesia with sodium considerably in excess of potassium, to those comparatively rich in silica, and poor in lime and magnesia, but with sodium still in excess of potassium. The lower limits approach basalt, and the upper limits border rhyolite.

The same gradual transition exists in the mineralogical composition. At one end are pyroxene-andesites with accessory olivine, the feldspars being rather basic plagioclase. These pass into pyroxene-andesites without olivine, and into hornblende-pyroxene-andesites, and hornblende-andesites, and with increasing amounts of quartz into dacite, or quartz-andesites. In the dacites the feldspars are: plagioclase, approaching albite, and sanidine; while biotite becomes prominent among the ferromagnesian minerals.

In considering the classification of such a series of rocks, since their mode of occurrence is the same throughout, namely, that of lava streams, Küch finds the grounds of classification to be: chemical composition, mineral composition and structure. Of these, chemical composition is undoubtedly that which under like conditions of solidification controls the mineral and structural

development of the rock. Consequently he concludes that upon purely theoretical grounds a chemical classification would be the most desirable. But from the present condition of our knowledge this would be impracticable.

Moreover, he observes, that while the chemical analysis of an unaltered rock furnishes us with the proportions in which the elements existed in the molten magma, it is very probable that rocks of like chemical composition may have been derived from magmas consisting of quite different silicates (that is, possessing different molecular constitutions). And this he suggests is one of the reasons why eruptive rocks with corresponding analyses can exhibit quite different mineralogical compositions. In a foot note he observes that another cause for this phenomenon may lie in differences in the process of solidification, which may affect the rearrangement of the compounds originally in the magma. To this extent the mineralogical composition is dependent on the genesis of eruptive rocks, which he considers essentially the same as their geological mode of occurrence.

Since we are not in a position to infer the original molecular constitution of a magma from its chemical analysis, he does not consider a chemical basis of classification applicable. Nevertheless he states that a comparison of the chemical composition of the andesitic lavas with their mineralogical composition shows that certain differences of chemical composition go hand in hand with others of mineral development, and with these are also connected modifications of structure.

The mineralogical features are the most pronounced, and are therefore selected as a basis of classification. The first subdivision is based on the presence or absence of quartz, and the groups become andesites and dacites. They are not, however, distinctly separated from one another, being connected by gradual transitions. But this grouping, as a purely mineralogical one, fails, as he himself points out, in cases where quartz has not crystallized, as in certain dacitic glasses.

In the further subdivision of these groups the ferromagnesian minerals are employed as distinguishing characteristics, and the

following divisions are established under andesite: Pyroxene-andesite, hornblende-pyroxene-andesite, and hornblende-andesite. Under dacite: Pyroxene-dacite, pyroxene-hornblende-dacite, biotite-hornblende-dacite. As already remarked, the mineralogical gradation from pyroxene-andesite to biotite-hornblende-dacite is by very gradual transitions. Biotite is most abundant in the most silicious varieties.

The microscopical character and the distribution of the porphyritical minerals and of the groundmass, and the relation between the microstructure of the latter and the composition of the rocks are described in detail, and appear to be identical with those existing in the andesites and dacites of western North America. These descriptions are presented in the most satisfactory manner, but need no special notice except to call attention to the occurrence of microlites of quartz in the form of minute pyramids .003 mm. in diameter, which are an essential component of the glassy groundmasses of numerous dacites. Precisely similar microlites of quartz have been observed by the present writer in certain silicious glasses in the Yellowstone National Park, the descriptions of which have not yet been published.

The chemical composition of the rocks is shown by fifteen complete analyses and ten silica determinations. They range from 54.21 per cent. of silica to 70.22 per cent. The analyses were made from perfectly fresh and unaltered rocks, and the high percentage of water found in some cases, which reaches 3.62 per cent., is referred to the glass base. This is sometimes markedly pearlitic and hydrated. The variations in the proportions of the chemical components throughout the rock series is pointed out, and is correlated with the variations in the mineral constituents.

Attention is called to the fact that a frequent mode of alteration among these lavas leads to the development of opal, and the consequent increase in the silica percentage, so that a determination of the silica in a rock may be misleading unless the rock is known to be unaltered.

Dr. Küch's report is to be commended, not only for its scientific excellencies, but also for the form in which it has been published, and the admirable indices which render its details easily accessible.

The facts brought out by this report lead the present writer to certain conclusions regarding the nature of the volcanic ejections of the South American Andes of the greatest importance, which, however, may be modified as our information becomes more complete. In brief, it appears that the main mass of the lavas of all the volcanoes of the Andes is andesite, of variable composition in all localities. It grades into basic varieties, approaching basalt, in some places, and into acid varieties which are dacites, in others. It is probable that the basic varieties would be classed as basalts by many petrologists, but they would not constitute the more basic forms of basalt. The variability in composition and petrographical characters within these limits is pronounced, and proves the intimate relationship between all of the lavas. The almost universal absence of the most basic and most acid members of the series which occur in other regions, namely, the true basalts and rhyolites, is most significant, and, if established by future investigation, would indicate that volcanic activity in the Andes, which is still in force, had developed, by the differentiation of some magma common to the whole great Cordilleran system, a series of lavas of limited range. This series, though precisely similar to parts of others developed in other regions, especially those of Tertiary age in western North America, is wanting in the extreme forms of differentiation common to the latter—that is, in basic basalt and rhyolite. From this we may infer that the general differentiation of the magma supplying the lavas of the Andes has not reached its final stages, in which great volumes of extremely differentiated material will have been developed. It would seem to be in a much less advanced condition than the magmas supplying the lavas in Central America and Mexico, which are in turn less advanced than those of the United States, where volcanic activity is extinct or at least quiescent.

It is not to be expected that all of the volcanoes of the Andes are in exactly the same phase of differentiation, which they undoubtedly are not, but in a general way they have not progressed beyond the limits of olivine-bearing pyroxine-andesite and dacite, and may be considered as having the basalt and rhyolite phases before them. They thus show themselves as comparatively young, or perhaps middle-aged. It will be observed, however, that rhyolite occurs in small amount in Ecuador, as shown by analyses 14 and 15 in Table II.

The chemical similarity of the magmas of the Andes with those of general occurrence in western North America, which are fairly represented by the volcanic rocks of the Yellowstone National Park, is seen upon constructing a diagram of the molecular variation of the essential constituents in a manner employed by the writer[1] and also by Dakyns and Teall[2] in discussing the differentiation of molten magmas.

In Table I are given the chemical analyses of perfectly fresh rocks from Colombia, published by Dr. Küch. The general molecular character of the magmas is shown by diagram I. In the lowest part of the diagram the molecular variation of all of the essential constituents is represented, that of silica being given by the abscissas, the zero point being some distance to the left. In the middle part of the diagram alumina, soda and potash are separated from the lime, magnesia and iron-oxide, which are given by themselves in the uppermost part of the diagram, in order to avoid the confusion of lines in the lowest part. The iron is represented as ferrous oxide. The character of this diagram is quite similar to that of the diagrams for the rocks from the Yellowstone National Park in the paper on the origin of

[1] Iddings (J. P.). The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park. Bull. Phil. Soc., Washington, 8vo. Washington, 1890. Vol. 11, pp. 191–220.

——. The origin of igneous rocks. Bull. Phil. Soc., Washington. 8vo, Washington, 1892. Vol. 12, pp. 89–214, Pl. 2.

[2] Dakyns (J. R.) and Teall (J. J. H.). On the plutonic rocks of Garabal Hill and Meall Braec. Quart. Journ. Geol. Soc. 8vo. London, 1892, May 2, Vol. 48, part 2, No. 190, pp. 104–120.

TABLE I.

Chemical Analyses of Volcanic Lavas from Colombia.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
SiO_2	56.91 .948	57.24 .954	59.13 .985	60.05 1.000	61.04 1.017	61.09 1.018	61.26 1.021	63.36 1.056	63.50 1.058	63.56 1.059	65.39 1.089	66.03 1.100	67.30 1.121	68.41 1.140	69.56 1.159
TiO_2				.85	.45	.95				.95					
Al_2O_3	18.18 .178	18.02 .176	17.00 .166	15.59 .152	15.72 .154	15.96 .156	16.15 .158	16.35 .160	15.34 .150	15.43 .151	15.49 .151	14.57 .142	17.55 .172	16.08 .156	15.65 .153
Fe_2O_3	4.65 .029	3.46 .021	7.03	6.95 .043	5.03 .031	4.29 .026	4.39 .027	2.12 .013	3.22 .020	3.02 .018	2.80 .017	2.57 .016	1.47 .009	2.12 .013	1.24 .007
FeO	3.61 .050	4.13 .057		.65 .009	2.15 .029	2.03 .028	2.66 .037	3.05 .042	1.71 .023	2.43 .033	1.99 .027	1.19 .016	1.67 .023	1.44 .020	.91 .011
MgO	3.49 .087	3.77 .094		3.61 .090	3.61 .090	1.06 .026	2.91 .073	3.28 .082	2.50 .062	2.55 .064	2.06 .051	1.89 .047	1.04 .026	1.14 .028	.82 .020
CaO	7.11 .127	7.78 .138	6.67 .119	6.43 .114	5.34 .095	6.66 .115	5.75 .102	4.79 .085	4.31 .077	4.33 .077	4.48 .080	3.38 .060	3.48 .062	3.52 .063	2.52 .045
Na_2O	4.02 .064	5.54	4.80 .077	3.83 .061	4.02 .064	2.89 .046	4.93 .079	3.58 .057	4.84 .078	4.02 .064	4.56 .073	3.71 .059	3.90 .063	4.52 .073	4.09 .066
K_2O	1.61 .017		1.37 .014	1.76 .018	2.66 .028	2.51 .026	2.65 .028	2.92 .031	2.75 .029	2.41 .025	1.59 .016	2.70 .029	2.13 .022	2.24 .023	2.19 .023
P_2O_5	.25			.25		.22		.13		.17	.11	.09	.13	-	.13
SO_3										.05					
H_2O	.36	.06	.16	.47	.58	1.44	.15	.99	1.99	1.09	.55	2.07	.80	.33	2.92
	100.19	100.00		100.44	100.60	99.10	100.85	100.57	100.16	100.01	99.02	98.20	99.47	99.84	100.03

1. Pyroxene-andesite. N. W. foot of the Purgatorio. Pasto.
2. Olivine-pyroxene-andesite. Pasto.
3. Pyroxene-andesite. Cerro negro de Mayasquer.
4. Pyroxene-andesite. Azufral de Túquerres.
5. Hornblende-andesite. Peñon de Pitayó.
6. Hornblende-andesite. Loma de Ales.
7. Pyroxene-andesite. Lava of 1869. Pasto.
8. Hornblende-pyroxene-dacite, (with olivine and biotite) Cerro negro de Mayasquer.
9. Hornblende-pyroxene-dacite. Chiles.
10. Hornblende-dacite. (With biotite and pyroxene.) Llanos de las Mesas, Tajumbina.
11. Pyroxene-dacite. Cumbal.
12. Hornblende-pyroxene-dacite. Hondon, Chiles.
13. Hornblende-biotite-dacite. Azufral de Túquerres.
14. Hornblende-biotite-dacite. Azufral de Túquerres.
15. Hornblende-biotite-dacite. Loma de Ales.

TABLE II.

Chemical Analyses of Volcanic Rocks of the Andes.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	52.02	56.50	57.10	58.00	58.35	59.28	60.32	62.35	63.00	63.19	63.49	63.69	66.06	72.46	73.61
	.867	.941	.951	.966	.972	.988	1.005	1.039	1.050	1.050	1.058	1.061	1.101	1.207	1.227
TiO_2						tr				.18					
Al_2O_3	17.14	15.06	17.25	18.00	16.74	18.14	16.92	17.32	18.40	18.65	12.42	15.03	15.64	12.80	12.01
	.168	.147	.169	.176	.164	.177	.165	.169	.180	.183	.121	.147	.153	.125	.117
Fe_2O_3	7.94	} 13.52	} 10.75	3.72			5.88	4.51	3.96	4.01	6.41	2.51		2.32	2.27
	.049			.023			.036	.028	.024	.025	.040	.015		.014	.014
FeO	3.52			2.73	6.71	8.79	1.40			1.89	1.34	2.41	3.90		
	.048			.037	.093	.122	.019			.026	.018	.033	.054		
MnO	.85				.54	tr		.04	.10	.13	.85	.55	.71		
MgO	3.13	2.72	2.50	3.56	4.84	3.43	3.52	3.60	3.71	1.20	1.32	.80	2.57	tr	.20
	.078	.068	.062	.089	.121	.086	.088	.090	.093	.030	.033	.020	.064		.005
CaO	11.57	6.23	5.00	6.96	6.81	4.49	5.64	5.43	5.36	4.86	4.17	3.30	4.53	1.35	.89
	.206	.111	.089	.122	.121	.080	.100	.097	.095	.086	.074	.059	.080	.024	.015
Na_2O	2.38	4.55	5.12	4.36	4.69	4.26	3.83	4.29	4.22	3.69	4.90	6.54	4.00	4.48	4.34
	.038	.073	.082	.070	.075	.068	.061	.069	.068	.059	.079	.105	.064	.072	.070
K_2O	.60	1.35	2.10	2.12	1.18	1.85	2.42	3.13	2.36	1.95	1.78	2.46	2.36	4.11	3.82
	.006	.014	.022	.022	.012	.019	.025	.033	.025	.020	.019	.026	.025	.043	.040
P_2O_5	tr									.15	tr	tr			
H_2O	.28	.30	.25	.32	.31		.44	.13	.36	.07	2.88	2.23	.30	2.92	3.35
	99.45	100.23	100.07	99.77	100.17	100.24	100.37	100.80	101.47	100.07	99.56	99.52	100.09	100.44	100.53

1. Portañuela, Volcano Yate, Southern Chili.
2. Tunguragua, Ecuador.
3. Chimborazo, "
4. Chimborazo, "
5. Tunguragua, "
6. Carahuirazo, "
7. Chimborazo, "
8. Pichincha, "
9. Cachutafruto, Ecuador.
10. Tajumbina, Colombia.
11. Volcano Yate, Southern Chili.
12. Volcano Yate, "
13. Tunguragua, Ecuador.
14. Guamani, Tablon de Itulgache, Ecuador.
15. Oyacachi.

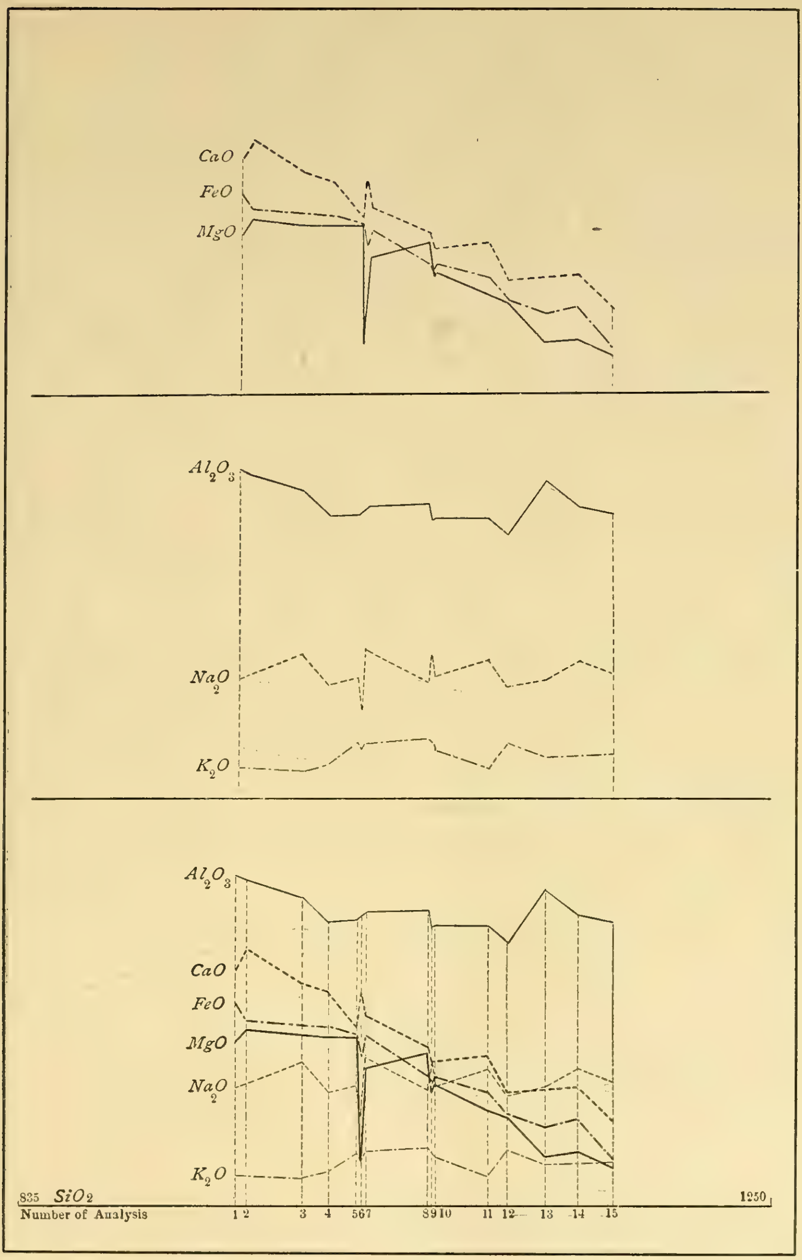


DIAGRAM I.—Molecular variations in lavas of Colombia.

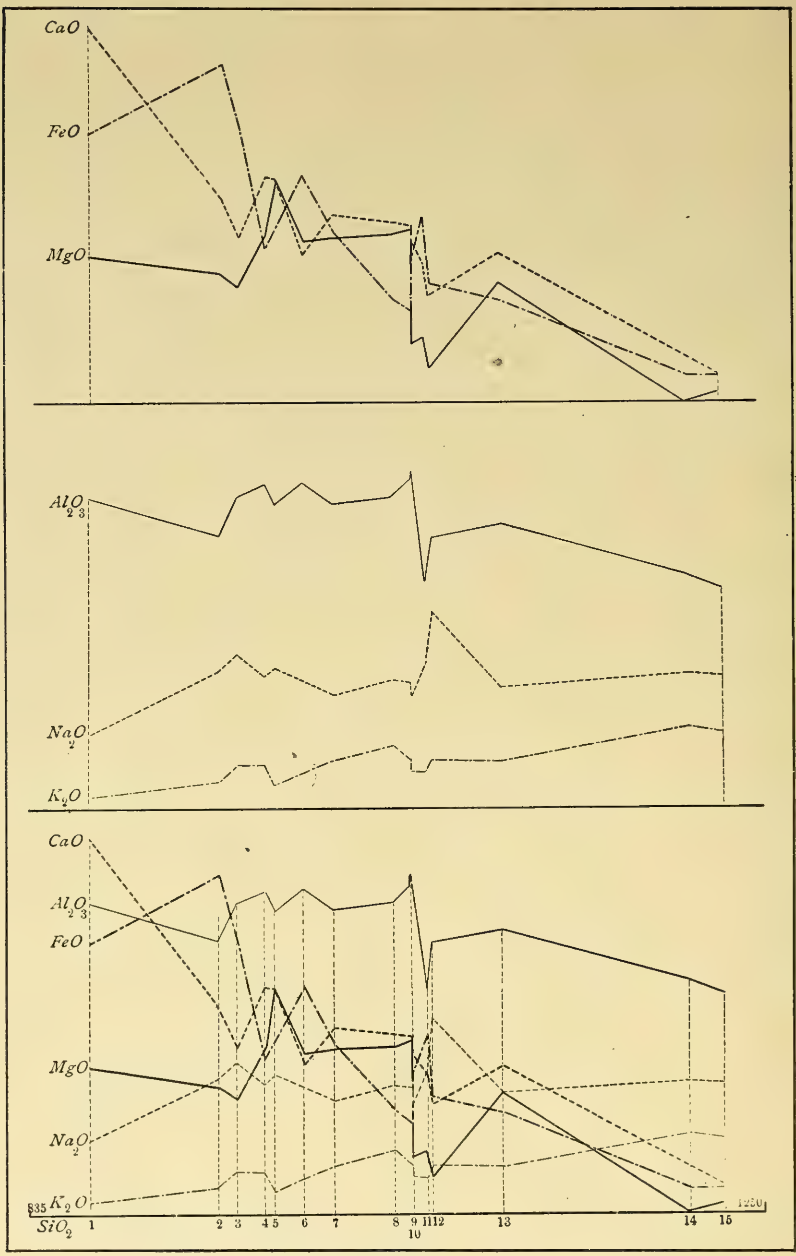


DIAGRAM 2.—Molecular variations in lavas of the Andes.

igneous rocks already cited. There is nearly the same relation between the alkalies and alumina, the soda being still more in excess of potash, and both increasing gradually toward the more silicious end of the series. The alumina maintains a high position, gradually decreasing. The lime, iron-oxide and magnesia decrease rapidly from the less silicious to the more silicious end of the series, and lie somewhat close together. In one instance there is a marked drop in the magnesia.

In Table II are given the analyses of lavas from the Andes south of Colombia, with one exception, as they have been recorded in Roth's tables of rock analyses. They present a somewhat wider range of silica percentages, from 52.02 to 73.61, but whether they have all been made from unaltered rocks is not known to the writer. An analyis of "obsidian" from Colombia is omitted, since it is extremely crude, giving 75 per cent. of silica and 3 per cent. of magnesia, with no lime. Diagram 2 expresses the molecular variations among the rocks included in this grouping. They have the same general nature as those just described, especially as to the alkalies and alumina; but the lime, iron-oxide and magnesia are more variable, which may represent the true condition of the case, or may be due to imperfect methods of analysis.

It is evident from these diagrams that the lavas of the Andes represent various phases of the differentiation of a magma which is chemically similar to that which has furnished the lavas of the Great Basin and extreme western Cordilleras in the United States, and that they belong to similar petrographical provinces.

JOSEPH P. IDDINGS.

ON THE USE OF THE TERMS POIKILITIC AND MICROPOIKILITIC IN PETROGRAPHY.

It is evident that descriptive petrography needs some generally accepted term for both a macroscopic and microscopic rock structure which is, in a certain sense, intermediate between those known as the *granular* or *microgranitic* and *graphic* or *micropegmatitic*. Areas have been observed and variously described in many types of massive rocks, whose component minerals possess neither the complete independence of optical orientation characteristic of granular structures, nor the entire optical continuity of the separated portions of two interpenetrating crystal individuals. These areas are in fact occupied by a comparatively large individual of one mineral which is more or less completely filled with crystals or grains of other minerals, arranged with no reference to one another or to their host. This structure does not usually appear as distinct from the granular except when seen as a mottling of a large cleavage surface of the enclosing mineral in a hand specimen, or as an irregular spotting of a uniformly extinguishing area under the microscope. In ordinary light, such an area may appear quite granitic, but between crossed nicols it is very distinctive.

Like the graphic or micropegmatitic structure, this relation is most commonly observed between quartz and feldspar, especially in the groundmass of quartz-porphyries; but, like that structure, it is also by no means uncommon between many other species.

Essentially this structure was figured and described at length by the writer in a quartz-porphyry from near Tryberg, in the Black Forest, in 1883,[1] although no particular name was at that time given to it. In 1886 the writer proposed the term *poikilitic*

[1] Neues Jahrbuch für Min., etc., Beilage bd. II, p. 607. Plate XII, figs. 3 and 3[a], 1883.

(ποικὶλος, mottled)[1] for the macroscopic equivalent of this structure which is characteristic of the hornblende of the Stony Point hornblende-picrite or cortlandtite, as it is also of the Baste and Schriesheim *schillerfels* of Germany. This had before been called "*luster mottling*," by Pumpelly[2] and Irving,[3] but this name is not capable of application to other allied structures of different appearance. In 1887 the writer described this macro-poikilitic structure in the orthoclase phenocrysts of an orthoclase-norite, belonging to the Cortlandt series.[4]

Though it is not uncommon in many minerals, it is less important and less frequent than the micropoikilitic structure in the groundmass of acid porphyritic rocks of all ages. When studying the ancient quartz-porphyries of Missouri for his thesis, Prof. E. Haworth encountered it and applied to it for the first time the name *poecilitic*.[5] In this connection the writer furnished Dr. Haworth the following from his lecture notes:

"A holocrystalline groundmass contains no amorphous or unindividualized matter whatever, and independently of differences occasioned by variations in the fineness of grain, three quite distinct types of holocrystalline structure are distinguishable. These three types are conditioned by the mutual relation of the quartz and feldspar crystals, which compose the groundmass. In the first place they may be wholly independent, thus giving rise to a granular aggregate which is well designated by the term *Microgranitic Structure*.

"In the second place a granular effect may be produced by the complete interpenetration of two individual crystals of the same size. In this case—due to the simultaneous crystallization of the two minerals from the magma—all the parts of the same individual, no matter what the size or shape, must

[1]American Journal of Science (3[d] ser.), vol. 31, p. 30, Jan., 1886. This term was at first incorrectly spelled *poicilitic* and subsequently corrected by Prof. Dana to its Latin form, *poecilitic* (*ib.* vol. 33, p. 139, Feb., 1887). Its preferable orthography is, however, that given above. At the time it was proposed the writer was not familiar with Breithaupt's name, *poikilit*, for bornite, nor with the designations, *terrain poecilien*, *poecilitic* and *poikilitic*, given successively by Brongniart (1829), Conybeare (1832) and Buckland (1837) to the "New Red" sandstone (cf. Bridg. Treat. II., p. 38). The totally different application of these terms could, however, produce no confusion with the one now proposed, even if they were not obsolete.

[2] Proc. Am. Acad., vol. 13, p. 260. Boston, 1878.

[3] Monogr. U. S. Geol. Survey, vol. 5, p. 42, 1883.

[4] American Journal of Science, (3[d] ser.) vol. 33, p. 139, 1887.

[5] Am. Geologist, vol. 1, pp. 368, 369; Pl. I, fig. 1, June, 1888.

have exactly the same optical orientation, and must hence extinguish the light between crossed nicols together. Such a structure is termed, according to the particular form it assumes, *micropegmatitic* or *granophyric*.

"In the third place a single large crystal of one of the two constituents of the groundmass may be filled with much smaller, irregularly arranged grains or crystals of the other. This would also give the general effect of a finely granular structure, although it is essentially different from either of the others above mentioned." [1]

The same structure was briefly described by Teall in a quartz-felsite from the Cheviot Hills, but without any particular designation being applied to it.[2] Harker also mentions a variety of the same structure as common in the ancient rhyolitic lavas of Wales.[3] Cross described the macro-poikilitic structure in a hornblende-peridotite, from Custer county, Colorado,[4] and the micropoikilitic structure in a rhyolite from Silver Cliff in the same district, although the connection between the two was not mentioned. In speaking of the latter rock, he says of the groundmass:

"There seems to be no isotropic matter, but individual characteristics of form and optical action are lost through the minute size of the grains which overlap and overlie each other in the thinnest attainable sections. This mixture is irregular in many cases, but in others a mottled appearance is produced in that one substance attains a uniform optical orientation in certain areas, but is filled by inclusions of the other substance. No regular intergrowth of the two can be discovered. In some spots it was clearly quartz which was the enveloping mineral." [5]

Brögger has described the groundmass of a quartz-porphyry from the region of Christiana as having a typical poikilitic structure.[6]

In his recent monograph on the Eruptive Rocks of Electric Peak and Sepulchre Mountain in the Yellowstone Park, Iddings describes the micropoikilitic structure in the groundmass of certain dike porphyrites, where he for the first time makes use of exactly this term.[7] In speaking of the Sepulchre Mountain dikes,

[1] Loc. cit. pp. 367, 368. [2] British Petrography, p. 343. London, 1888.

[3] The Bala Volcanic Series. Cambridge, 1889, pp. 22, 23.

[4] Proc. Colorado Scientific Society, vol. 2, p. 242. 1888.

[5] Ib., p. 232. [6] Zeitsch. für Kryst. u. Min., vol. 16., 1890., p. 46.

[7] Twelfth Ann. Rept. U. S. Geol. Survey, p. 589. 1892.

he calls it a "patchy structure," but says it is identical with what he before called the micropoikilitic (micropoicilitic).[1]

The micropoikilitic structure is extremely abundant in the ancient acid lavas of South Mountain,[2] in southern Pennsylvania and Maryland. It can there be proved in some cases to be of secondary origin as it occurs in plainly devitrified glasses, and it is the writer's opinion that such enclosing quartz areas will, in many cases, prove to have originated subsequent to the solidification of the rock.

I am not aware that either the macro- or micropoikilitic structures have been directly recognized by the German petrographers. I am indebted to Prof. L. V. Pirsson of New Haven for the information that the latter is recognized in France, although we have been unable to find any definition of it in print. He has shown me a section of a quartz-porphyry from Georgia, with a groundmass exactly like those from South Mountain, which Fouqué examined and pronounced an admirable example of the "*type épongeuse*," sometimes called "*structure pétrosiliceuse à ponce*." It is clearly not the same as Michel Lévy's *structure globulaire*, which he defines: "Sphérolites radiés, imprégnés de quartz orienté dans un sens optique unique. Globules imprégnés de quartz orienté, auréoles,"[3] because there the included matter is radially arranged, while in the micropoikilitic structure it is wholly irregular in its arrangement.

The references given above are sufficient to demonstrate the frequency of the rock structure here mentioned, and to show the desirability of some term to describe it. It is therefore proposed that *poikilitic* and *micropoikilitic* be employed for rock structures, whether primary or secondary, conditioned by comparatively large individuals of one mineral enveloping smaller individuals of other minerals, which have no regular arrangement in respect either to one another or to their host.

GEORGE H. WILLIAMS.

[1] Ib., p. 646.

[2] American Journal of Science, (3^d ser.) vol. 44, p. 482, Dec., 1892.

[3] Roches Éruptives, p. 29. Paris, 1889.

Studies for Students.

THE MAKING OF THE GEOLOGICAL TIME-SCALE.

A critical examination of the nomenclature applied to the several divisions of the geological scale reveals a strange mixture of names, the reason for which is not evident to modern students of the science. In the list of system-names we find Carboniferous and Cretaceous, indicative of mineral characters, associated with Tertiary and Quaternary, meaning rank in some undefined order of sequence. The presence of these terms is no less mysterious than the absence of grauwacke and old-red sandstone, and primary and secondary, which were originally included. Triassic is the name of another system and records the three-fold division of the system of rocks to which it was applied; and Devonian, the name of another, reminds us of the county in England in which its rocks were first named. Observing these things, one is tempted to call in question the reliability of a systematic classification so heterogeneously compounded.

Although the older living geologists can remember back almost to the beginnings of the science, those who now are beginning their study of geology may find profit in examining the foundation principles, and the systems which have been devised, and have led to the construction and belief in the present classification — a classification, the adoption and unification of which has been thought worthy of the organization and continuance of an international Congress of Geologists. It is needless to call attention to the necessity of some systematic classification of geological formations, but as a foundation for the scientific study of the history of organisms there is need of a time-scale running back into the past, the degree of accuracy of which is known as well as the extent of its unreliability. In early attempts to classify

rocks the chronological element of the scale was not considered, but by degrees the classification has passed from a classification of rocks to a classification of periods of time.

The ancients in many respects were keen observers; they knew much about plants, animals, physical and chemical phenomena, and astronomy. But with all their learning, there appears to have been no conception formed of an ancient history of the globe and its inhabitants prior to the earlier centuries of the Christian era. One of the first geological phenomena to become generalized into a theory was that of the formation of mountains by earthquakes, as cited by Avicenus in the tenth century. The gradual change of relative level of land and sea, as seen in the encroaching of the sea or the departure of sea from the shore, gave rise to speculations regarding the great length of time required for the lifting of the whole land by this means. In the sixteenth century, Lyell reminds us, attention was drawn to the meaning of fossils, and dispute arose as to their nature. Leonardo da Vinci doubted the then current belief that the stars were the cause of the fossil shells and pebbles on the mountain sides, and advanced the idea "that the mud of rivers has covered and penetrated into the interior of fossil shells at the time when these were still at the bottom of the sea near the coast" (Lyell's Principles, p. 34).

By degrees, as Lyell has described in such fascinating manner, one after another the foundation principles arose, were discussed, controverted, and finally, by their intrinsic truth, became established. But it was not till nearly the beginning of the present century that enough was known of rocks for the formation of a general systematic classification of geological formations. The belief in a limit of six thousand years for the formation of the world was prevalent. Catastrophy was the universal resort for explanation of phenomena not then understood. And for geological purposes the Noachian deluge was an indispensable agent for the scientific explanation of even the conspicuous phenomena. For these reasons inquiry did not reach into the antiquity of the geological ages. And the first attempts at classi-

fication took little or no account of actual time-factors in geology.

Lehmann[1] (Johann Gottlob Lehmann died in St. Petersburg, 1767) is generally credited with having first proposed a classification of rocks on the basis of the order of their formation, as Primitive, Secondary, and a third class, the modern or superficial rocks made by the deluge or ordinary river action. Lehmann recognized also a direct relation of origin of the Secondary from the Primitive rocks, and thus arose the beginnings of the geological time-scale. Lehmann recognized three originally distinct kinds of rocks, or rock formations. The volcanic were separated from the others because having no particular connection with either in origin. The distinction, however, between Primitive and Secondary was fundamental. The Primitive was strictly the original, basal rock formed by crystallization from chemical solution before organisms lived; and the Secondary rocks were of secondary origin, made out of fragments of the older and always lying above them. In the original classification of Lehmann, Secondary included all the stratified rocks, as we now consider them, and in the classifications following Lehmann for some years the term Secondary was applied, though in a restricted sense.

Cuvier and Brongniart proposed the name Tertiary for the rocks classified as Secondary by Lehmann, but lying above what is now known as the Cretaceous system; and Quaternary was introduced by Morlot in 1854 for the rocks of superficial position and of glacial or fluviatile origin. Thus the nomenclature of Lehmann, which was proposed originally to indicate the derivation of the Secondary from the Primitive, was expanded on the basis of stratigraphic succession, and we observe the anomaly of a retention of two names (Tertiary and Quaternary), formed on the principle of Lehmann's terms, but his own terms, as well as his theory as a basis of classification, entirely discarded.

[1] J. G. Lehmann, Versuch einer geschichte von floetz-gebürgen, etc., Berlin, 1756. French translation cited by Lyell. Essai d'un Hist. Nat. des Couches de la Terre, 1759. See Lyell, "Principles," Vol. 1, p. 72, and Conybeare and Phillips "Geology," p. vi, and p. xlii.

Werner (1750-1817) elaborated Lehmann's scheme and modified it. He was the great teacher of geology at Freiburg, Germany, in 1815, and left his impress upon the geologists of the time, though he wrote little in the way of systematic exposition of his theories of classification. He adopted Lehmann's *Primitiv Gebirge*, but of the Secondary rocks he made a lower class, which he called transition rocks (*Uebergangsgebirge*), which were stratified, contained none or but few fossils, and were more or less oblique in position; these characteristics were observed in northern Europe, where he studied them. The remainder of the original Secondary rocks, he called *Floetzgebirge*, or flat-lying formations, and these were the equivalents of Lehmann's Secondary in the classification of the early part of the century. Later, the Wernerian school called the formations above the Cretaceous *neues Floetzgebirge*, to which, as they were studied in the Paris basin, Cuvier and Brongniart, in the latter decade of the last century, applied the name *Tertiary*, which still remains in the scheme. Werner called the looser, overlying, unconsolidated rocks *angeschwempt Gebirge*, or alluvial formations, which were afterwards, as above stated, called Quaternary by Morlot.

The classification of Lehmann, as perfected by Werner, was then as follows:

German names.	*English equivalents.*
IV. Angeschwempt gebirge,	Alluvial formations.
III. *b.* Neues Floetzgebirge,	Tertiary "
a. Floetzgebirge,	Secondary "
II. Uebergangsgebirge	Transition "
I. Urgebirge	Primitive "

These were the formations which made up the geological series as then recognized. Volcanic rocks were looked upon as local formations, and of small account in general classification. But they came to be more deeply studied by Werner, and his notion that trap was of aqueous origin led to much controversy, and gave chief prominence to his views (the Neptunian theory) and to that classification of rocks which will be next considered.

The rocks of igneous origin, although sometimes interstratified with sedimentary rocks, do not enter into the present geological time-scale, and for the present purpose further consideration of their classification is unnecessary. There has always been a remnant of rocks at the base of the scale, the consideration of which may be discarded here, because it is known chronologically only as below those rocks of which distinct evidence of their relative age is apparent. The name Primitive has been changed to Primary, and finally to Archæan, a name which was proposed by Dana, and is likely to be retained for some of the basal part of the series.

This first comprehensive classification of rocks may be called the Lehmann classification. It was based upon a structural analysis of the rocks in the order of their actual positions. The nomenclature is applied on the theory of relative order of formation.

Richard Kirwan (Geological Essays, London, 1799), claimed to be the first author to publish a general treatise on Geology in the English language. Although the book is written in a decidedly controversial spirit, the author appears to have had a thorough acquaintance with the various treatises in French, German, Latin and English, in which were expressed contemporaneous opinions regarding geological science. He was a Fellow of the Royal Societies of London and Edinburgh, member of the Royal Irish Academy, and of Academies in Stockholm, Upsala, Berlin, Manchester and Philadelphia, and Inspector General of his majesty's mines in the Kingdom of Ireland. It is probable, therefore, that he presents a fair idea of the opinions which underlay the Lehmann classification. According to Kirwan's book the rocks were originally in a soft or liquid state, the center of the earth was supposed to be hollow, or the whole earth was a solid exterior crust with immense empty caverns within. The materials of the earth were then in a state of fusion or solution, and by condensation, as time progressed, the solids were crystallized out and deposited from the chaotic fluid. The water contracted the surface and lowered upon it by sinking into the interior cavities. With the deposition of the primitive rocks

from the chaotic fluid, the water became purer. Mountains were conceived of as the local points of original crystallization which drew to them, in the process, the minerals from the general fluid. As the waters gradually withdrew by evaporation and sinking into the interior caverns, they became clarified and capable of supporting organic life.

Kirwan says (p. 26): "The level of the ancient ocean being lowered to the height of 8,500 or 9,000 feet, then and not before, it began to be peopled with fish." (Under the name fish he included shell-fish, and all other petrifactions). The plains were formed of depositions from the water of argillaceous, siliceous and ferruginous particles, mingled with those derived by erosion from the already protruding mountains. All the rocks above the height mentioned, he observed, quoting from testimony of numerous travelers, are lacking in fossils; even the limestones are crystalline or "primative" limestones and marbles. These observations were cited in refutation of Buffon's "error" in claiming that all limestones were derived from comminuted shells. According to some authorities, primitive mountains should include rocks of even less height than 8,000 feet, and the occasional presence of fossils at a greater elevation was by them accounted for by their transference to that elevation by the deluge. This account of Kirwan's will suggest the way in which the rock formation came at to be first called "*gebirge*," or mountains. Rocks were supposed to lie as they were originally formed, and thus in classifying rocks the larger aggregates were naturally mountain masses. As the conception of movements in the earth's crust with folding and displacement came into the science, the idea of classification and grouping of rocks was retained, but that their grouping was based upon present massing above the surface as mountains ceased to be accepted as truth. In the German language the term "*Gebirge*" was retained, and apparently with restricted meaning. Kirwan apparently translated the term directly into English as mountains. *Formation* however took the place of *mountain*, as applied to rock classification, in the early part of the century.

Lehmann's classification, in so far as it goes, expressed established facts of nature. There are Primitive, Secondary, Tertiary and Quaternary formations, but the theory that they may be defined and determined by physical structure and present relative position is only approximately true. All crystalline rocks are not primitive, all the secondary rocks are not merely consolidated fragments of primitive rocks. Some of them are fully metamorphosed. All Tertiary rocks are not unconsolidated, as the Tertiaries of California illustrate, and we now know that altitude above the sea, or relative position of the various formations, are by no means uniform and form no criterion for their determination.

The next important advance in the classification of rocks was started by Werner and his pupils. It was a classification based upon the mineral constitution of the rocks. As the study of geology advanced Lehmann's classification was found difficult to apply with precision, and it was found to be unnatural in that rocks of apparently similar kind were dissociated, while rocks of unlike character were brought into the same class. And the mineral character and composition of rocks was found to be an accurate means of defining them. As the mineral characters became clearly understood, the rock masses received their names from the chief minerals in them, and finally the mineral nomenclature entirely superseded the nomenclature of Lehmann, and a second classification arose in which the theory of the original order of formation of the rocks gave place to the actual sequence of mineral aggregates, one after another, in examined sections of the earth's crust. In this study of minerals Werner was a conspicuous leader, and the classifications at the beginning of the present century were mainly his or adaptations of them. The form which the geological scale assumed in English geological systems is seen in typical form in Conybeare and Phillip's Geology of England and Wales, 1822.

Arranged in order from above downwards, it is as follows :

I. *Superior order.* (Neues Floetzgebirge, of Werner).

II. *Supermedial order.* (Floetzgebirge, "

(1) Chalk formation.
(2) Ferruginous sands.
(3) Oölitic system or series.
(4) { Red marle or New Red sandstone.
Newer Magnesian or conglomerate limestone.

III. *Medial, or Carboniferous order.*
(1) Coal measures.
(2) Millstone, grit and shales.
(3) Mountain limestone.
(4) Old Red sandstone.

De la Beche (Geology, 3d edition, 1833) carries out the system more completely, calling the first, or superior order, *Supercretaceous group*, and applying the terms *Cretaceous*, *Oölitic* and *Red sandstone* to three groups into which he divides the second order, and giving the third the name *Carboniferous group*. Below these he recognizes Werner's Grauwacke group, for what was the lower part of the original *Uebergangsgebirge* of his earlier classification, and below this were the *inferior stratified or non-fossiliferous rocks*, *and the unstratified rocks*. All of the names, it will be observed, are names indicative of mineral characters. If we turn back to the year 1817 we find the same Wernerian system applied to the classification of North American rocks by William Maclure (Observations on the Geology of the United States of America, Philadelphia, 1817). The author writes: "Necessity dictates the adoption of some system so far as respects the classification and arrangement of names. The Wernerian seems to be the most suitable, first, because it is the most perfect and extensive in its general outlines; and secondly, the nature and relative situation of the minerals in the United States, whilst they are certainly the most extensive of any field yet examined, may perhaps be found the most correct elucidation of the general accuracy of that theory, so far as respects the relative position of the different series of rocks." (Observations, etc., p. 28). The classification there set forth is as follows (in the order from below upwards):

Class I. *Primitive rocks.*

Class II. *Transition rocks*—including (1) transition limestone, (2) transition trap, (3) greywacke, (4) transition flinty slate, (5) transition gypsum.

Class III. *Floetz or secondary rocks*—including (1) old red sandstone, (2) 1st floetz limestone, (3) 1st floetz gypsum, (4) 2d variegated sandstone, (5) 2d floetz gypsum, (6) 2d floetz limestone, (7) 3d floetz sandstone, (8) rock salt formation, (9) chalk formation, (10) floetz trap formation, (11) independent coal formation, (12) newest floetz trap formation.

Class IV. *Alluvial rocks*—including (1) peat, (2) sand and gravel, (3) loam, (4) bog iron ore, (5) nagel fluh, (6) calc tuff, (7) calc sinter.

Notice in this classification that the "coal formation" is placed near the top of the secondary rocks, the "rock salt formation" near its middle, and the "old red sandstone" at its base. Later investigations did not confirm Maclure's opinion of the accuracy of Werner's system as applied to American rocks. Amos Eaton's classification of New York rocks (as exhibited in his "Geological and Agricultural Survey of the district adjoining the Erie Canal in the State of New York, Albany, 1824) is an elaboration of the same system.

In each of these classifications, except in a few cases of the retention of distinctions based upon the structural analysis, the whole nomenclature and classification is based upon mineralogical composition of the rocks. In the succeeding progress of the science a great part of the nomenclature has been replaced by other names composed on a different principle, but many of the divisions here recorded are still retained. This latter fact we may interpret to mean that distinctions based upon mineral or lithological characters are of some real and permanent value in geological classification. The history of development of this system from the first, or Lehmann's system, shows that the linear order of the series of formations in the list is based on the con-

ception of a time-scale, and a natural order of succession of the several formations.

The Wernerian classification in this respect was a correct one for the rocks in Northern Germany for which it was constructed. The English scale expressed the facts of sequence, so far as known, for the English rocks, but the attempt to fit either of them to the facts in North America emphasized their imperfection. The fundamental error in the Wernerian system was the assumption that the scale of Northern Germany was a universal scale, or, expressed in general terms, that the mineralogical constitution of a rock has any necessary relation to its place in the stratigraphical series.

The next step of progress in making the geological time-scale arose from the study of fossils. Fossils had been observed and recognized as organic remains for centuries before Lehmann and Cuvier. Lehmann, and he not the first, observed that Primitive rocks did not contain fossils, while Secondary rocks contained some, and what are now called Tertiary rocks contained them abundantly. But it was not until fossils were closely studied, their characters examined, and the species compared and classified that their importance was realized. Cuvier and Brongniart are generally credited with being the first to establish the scientific importance of fossils. (On the Mineral Geography and Organic Remains of the Neighborhood of Paris, 1808). In 1796 Cuvier had called attention to the fact that elephant bones discovered by him in the Paris basin were different from the bones of living species. In thus drawing a distinction between living and extinct animals, as implying present and past groups of living beings, the foundation was laid, not only of Palæontology, but of the whole field of investigation into the history and evolution of organisms. Cuvier and Brongniart, applying their methods of analysis to the rocks of the Paris basin, succeeded in classifying them into strata, and in defining the separate stratigraphical divisions in terms of the contained fossils. The Paris basin rocks being found to lie above the Cretaceous rocks of France and England, which represent the top member of the

secondary formation of the Lehmann classification, were named Tertiary to indicate their geological importance and their relative position in the geological scale. These naturalists did not, however, perfect the geological classification which their biological studies suggested.

William Smith in England ("Tabular view," 1790, and in unpublished maps and sections of the first and second decades of this century) emphasized the value of fossils as means of identifying strata in different regions, and others had some part in the elaboration of the principle involved, but Lyell more than any one else perfected the scheme of classification of geological formations on the basis of their fossil contents. We find him saying, in the second edition of his Elements of Geology, published in 1841, "When engaged in 1828, in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of Tertiary strata in four groups, and endeavoring to find characters for each, expressive of their different degrees of affinity to the living fauna" (p. 280). A mathematical comparison was made between the proportionate numbers of recent and of extinct species to the several divisions of the Tertiary rocks of England. The result is given in the following table (copied from his "Elements," 2d Ed., Vol. I, p. 284).

Period.	Locality.	Per Cent. of Recent Species.	Number of fossils compared.
Post-Pliocene,	Freshwater, Thames Valley,	99–100	40
Newer-Pliocene,	Marine Strata near Glasgow,	85– 90	160
Older Pliocene,	Norwich Crag,	60– 70	111
Miocene,	Suffolk, red and coralline crag,	20– 30	450
Eocene,	London and Hampshire,	1– 2	400

In the nomenclature here proposed Eocene is derived from the Greek ηως, dawn, and καίνος, recent; Miocene from μείον καίνος, less recent; Pliocene from πλειον καίνος, more recent, and the definite meaning of the nomenclature and the classification is to signify that the strata called Eocene contain the first traces of the fauna now living, the Miocene strata a small proportion of the living species, the Pliocene and Post-Pliocene more and still more of the living types, and that the whole of the Tertiary

is distinguished from the Secondary and all older beds by containing some representatives of the faunas now living.

In this earliest attempt to estimate time-relations by biological data, Lyell, as others of his time, considered species to be sharply defined natural groups, and therefore it was that the relations between a fossil fauna and its recent representatives could be expressed in mathematical terms, indicating the number of identical species. The principle underlying the classification, however, was of a deeper nature, and concerned the orderly succession of faunas and floras in time. From the application of this method of time-analysis to the Tertiary beds, it was extended to an analysis of the whole series of geological formations on the basis of their organic remains, and the Lyellian classification took the place of the older Lehmann classification as follows :

In place of	Tertiary	we have	Cainozoic.
" "	Secondary	"	Mesozoic.
" "	Transition	"	Palæozoic.
" "	Primitive	"	Azoic.

This latter classification and nomenclature was gradually built up, and mainly by English Geologists, as the Lehmann and Wernerian classification was largely elaborated by German and French Geologists.

Edward Forbes proposed to divide the known faunas and floras into two great groups, Neozoic (modern) and Palæozoic (ancient). The two terms Palæozoic and Protozoic were proposed about the same time. Palæozoic by Sedgwick, for the formations known to be fossiliferous, extending from his lower Cambrian upwards to include Murchison's Silurian system, and Protozoic was a provisional name proposed for pre-Cambrian rocks which might be found to contain fossils. (Sedgwick, Proc. Geol. Soc., Vol. II, p. 675, London, 1838).

In his Silurian System, Murchison proposed Protozoic in the following words : " For this purpose I venture to suggest the term " Protozoic Rocks," thereby to imply the first or lowest

formations in which animals or vegetables appear." (Murchison, Silurian System, p. 11).

Without entering into the delicate question of apportioning the honors due to each of these great English geologists (see *American Journal of Science*, Vol. xxxix., p. 167, 1890), it may be said that in this early usage of the terms, the distinction between Protozoic and Palæozoic was ideal—and in later developments, Palæozoic has been retained for that lower great division of the scale containing distinct remains of organisms, with the Cambrian system at the bottom. To show the connection with the older nomenclature, it may be noted that Palæozoic is equivalent to Primary fossiliferous, and in this system Azoic was applied to the Primitive rocks of the Lehmann system.

John Phillips, in 1841, proposed to extend the method of classification to the whole geological series, and as his scheme was apparently the first complete classification constructed on this basis, it is offered as it appeared in "Palæozoic fossils of Devon and Cornwall," London, 1841, p. 160 (see also Penny Cyclopædia, articles Geology, Palæozoic Rocks, Saliferous system, etc).

Proposed titles depending on the series of Organic Affinities.			*Ordinary title.*
Cainozoic strata	Upper	=	Pliocene Tertiaries.
	Middle	=	Miocene Tertiaries.
	Lower	=	Eocene Tertiaries.
Mesozoic strata	Upper	=	Cretaceous system.
	Middle	=	Oölitic system.
	Lower	=	New Red formation.
Palæozoic strata	Upper?		Magnesian limestone formation Carboniferous system.
	Middle?		Eifel and South Devon.
	Lower	=	Transition strata. Primary srata.

(The terms are founded on the verb. ζαω or ζωω—to live, combined with καινος recent, μεσος medial or middle, and παλαιος ancient).

Professor Le Conte has proposed Psychozoic, on the same principle for the latest geological period, in which man has appeared. (See Le Conte, Elements of Geology, New York). Lyell proposed to make, on this basis, a geological time-scale and applied the term Period to each of the several divisions of the scale. Thus we find in his Geology, second edition, published in 1841, a recognition of the time element in classification, without as yet the adoption of the biological nomenclature. He gives a table "Showing the order of superposition, or chronological succession, of the principal European groups of fossiliferous rocks. Under the heading "Periods and Groups" we find the following:

I. Post-Pliocene Period	A. Recent. B. Post Pliocene.
II. Tertiary Period	C. Newer Pliocene. D. Older Pliocene. E. Miocene. F. Eocene.
III. Secondary Period	G. Cretaceous group. H. Wealden group. I. Oölite, or Jura limestone group. K. Lias group. L. Trias, or New Red sandstone group. M. Magnesian limestone group. N. Carboniferous group. O. Old Red Sandstone, or Devonian group.
IV. Primary fossiliferous Period	P. Silurian group. ? Q. Cambrian group.

(Lyell, Elements of Geology, second edition, London, 1841. Vol. ii, p. 178).

Later Lyell adopted the biological nomenclature, and was prominent among geologists in developing and elaborating the idea of the successive appearance of new types of organisms coördinate with the progress of geological time.

One of the fullest elaborations of this biological classification of the geological series to form a time-scale is found in Dana's Manual of Geology. (Manuel of Geology; treating of the principles of the science with special reference to American Geological History, by James D. Dana, 3d ed., New York, 1880.) Here we find the larger divisions called times: I, Archean; II, Palæozoic; III, Mesozoic and IV, Cenozoic times. The Palæozoic time is classified into ages, viz: The age of Invertebrates, the Cambrian and Silurian; the age of Fishes, the Devonian; the age of Coal Plants, the Carboniferous. The Mezozoic is called the age of Reptiles. The Cenozoic time includes the age of mammals and the age of man.

Each of the ages is subdivided into periods and epochs, in which the stratigraphical groups and formations form the basis, and the particular faunas and floras of each constitute the data of determination for the time divisions. Thus the Devonian age includes the following:

Periods.

$$\left.\begin{array}{l}\text{Catskill}\\\text{Chemung}\\\text{Hamilton}\\\text{Corniferous}\end{array}\right\} = \text{Devonian Age;}$$

and, as an example, the Corniferous Period includes the following epochs:

$$\left.\begin{array}{l}\text{Corniferous}\\\text{Schoharie}\\\text{Cauda-galli}\end{array}\right\} = \text{Corniferous Period.}$$

The distinctions upon which these subdivisions are made are primarily stratigraphical, and we have still to seek a time-classification on a purely biological basis for the whole geological series.

One of the earliest attempts at systematic classification upon a purely biological basis, was made by Dr. Oppel in classifying the Jurassic formations on the basis of the successive Ammonites characterizing the beds. (A. Oppel, *Die Juraformation, Eng-*

lands, Frankreichs und des südwestlichen Deutschlands, 1856–1858). Oppel divided the lower part of the Jurassic system (the Lias) into 14 zones or beds; characterized successively from below upwards by their dominant fossil forms, chiefly ammonites.

Thus the successive zones were those of: 1, *Ammonites planorbis*; 2, *A. angulatus*; 3, *A. Bucklandi*; 4, *Pentacrinus tuberculatus*; 5, *A. obtusus*; 6, *A. oxynotus*; 7, *A. raricostatus*; 8, *A. armatus*; 9, *A. Jamesoni*; 10, *A. ibex*; 11, *A. Davœi*; 12, *A. margaritatus*; 13, *A. spinatus*; 14, *Posidonomya Bronnii*. Later classifications, elaborations or revisions of Oppel's system have been made by Wright, in 1860; Judd, 1875; Tate and Blake, 1876, etc. This method of classification recognized the principle of temporary continuance of species and of associated faunas; and it has been applied with greater or less success all through the geological scale of formations for the definition of the lesser divisions.

As early as 1838 the importance of the biological evidence in determining the time-scale was clearly enunciated by Murchison, who wrote in the introduction to the Silurian System, "that the *zoölogical* contents of rocks, when coupled with their order of superposition, are the only safe criteria of their *age*." (The Silurian System, p. 9).

The making of the geological time-scale has now progressed to the stage when it is pretty clearly seen that the ordinary classification of geological formations, as found in our text-books, includes two distinct series of facts: (1) *geological terranes*, arranged stratigraphically and classified by their positions relative to each other and by their lithological characters; and (2) *chronological time-periods*, which may be locally marked by the stratigraphical division planes, but which depend, fundamentally, upon biological evidence for their interpretation and classification. Gilbert[1] has concisely expressed the important fact of the purely local nature of the division-planes separating the formations stratigraphically into stages, series, systems or groups in

[1] Gilbert, G. K. The work of the International Congress of Geologists. Proc. Am. Ass. Adv. Sc., August, 1887. Vol. xxxvi., p. 191.

the words: "There does not exist a world-wide system nor a world-wide group, but every system and every group is local." "The classification developed in one place is perfectly applicable only there. At a short distance away some of its beds disappear and others are introduced; farther on its stages cannot be recognized; then its series fail and finally its systems and its groups."

If we accept the correctness of this statement, it is evident that geological terranes and the stratigraphical division-planes by which they are marked, although indicative of time succession, present nothing in themselves to indicate the particular place they occupy in a time-scale. Even were the age of a particular stratum in one section accurately determined by other means, there is no stratigraphical or lithological mark upon the rock stratum, by which the corresponding age can be recognized in another section. This is not meant to imply that it is impossible to trace a stratum or formation from one section to another in the same general geological province, for in such case it is a process of tracing with slight interruption the continuity of the one terrane. But when we pass from one basin to another, the physical continuity is broken, and the stratigraphy and lithology were made on a separate basis. Hence we reach the conclusion that the perfecting of the geological time-scale must be wrought by the means, primarily, of organic remains. Chronological time-periods in geology are not only recognized by means of the fossil remains preserved in the strata, but it is to them chiefly that we must look for the determination and classification of the rocks on a time basis.

This principle is clearly enunciated in the rules adopted by the United States Geological Survey for the direction of the survey.[1] "Among the clastic rocks there shall be recognized two classes or divisions, viz: structural divisions and time divisions." "The structural divisions shall be the units of cartography and shall be designated *formations*. Their discriminations shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic char-

[1] Report of the Director for the Tenth Annual Report, 1890, pp. 63–65.

acters change." . . . "The time divisions shall be defined primarily by palæontology and secondarily by structure, and they shall be called *periods*" (p. 65). We have thus reached the stage in the making of the geological time-scale in which the ideas of the *geological formation* and the *geological period* have become thoroughly differentiated. The geological period as a time-unit is primarily defined by the characters of the fossil remains in the rock, so that the elaborating further and making more precise of the geological time-scale must come from a direct study of the life history of organisms as recorded in the stratigraphical formations.

H. S. Williams.

Editorials.

The publication of Professor Wright's *Man and the Glacial Period* has been the occasion of much discussion concerning some of the questions with which the book deals. The numerous and somewhat elaborate reviews have criticized adversely many points in the volume; and in spite of the fact that Professor Wright has responded to most of the reviews, and in spite of the fact that both reviews and responses have been reviewed with loud professions of disinterested impartiality, it can hardly be claimed that any specific criticism of the book has been really met. The errors which have been pointed out, some of them trivial, many of them fundamental, still remain. The unjust claims and the misrepresentations of the volume deserved the measure of criticism they have received.

It was especially the author's handling of the evidence concerning the sequence of events in the glacial period, and concerning man's antiquity in terms of geology, which occasioned the somewhat prolonged discussion. Professor Wright is certainly entitled to his opinion on both these questions, as on all others. So far as we know, this right has not been disputed. The point of criticism at the outset was that the author did not fairly represent the present state of scientific opinion on these two questions, in a book which especially professed to set forth the present status of the problems with which it dealt. The justice of the criticisms made on this basis can not be questioned. The attitude of the reviewers, or at any rate the attitude of those who called forth the discussion, was not so much that there were two or more glacial epochs, though they indicated that this was their belief, as that the author had failed to adequately present the evidence bearing on the question, and had left the discussion on this point in such shape as to mislead the public, for

whom the book was professedly written, concerning the real condition of scientific opinion. The attitude of the reviewers who first criticized the work was not that glacial man did not exist, but that the author had failed to represent the present state of scientific opinion on this question, and that existing evidence does not, in the minds of many competent observers, bear out the conclusion which Professor Wright advances, and which he advances as if it were not open to question. Instead of answering or attempting to answer the criticisms passed on the book, the responses to the reviews, and the reviews of the reviews have diverted, or attempted to divert, attention from the real criticisms, to other matters. They have shifted, or attempted to shift, the discussion from the *presentation* of the above questions in the volume under review, to the merits of the questions themselves. Shifted to this basis, the questions at issue are very different from those first raised, and may continue to be discussed long after *Man and the Glacial Period* has ceased to attract attention.

If the discussion is not at an end, it is presumably near it. Incidentally, two questions which had previously been clearly recognized and sharply emphasized by specialists have been brought into greater popular prominence than heretofore. The one question concerns the simplicity *versus* the complexity of the glacial period. The other concerns the nature of the evidence which is to be admitted into court touching the question of man's geological chronology. The first of these questions has been long before the geological world, and little that is new has been added in connection with the recent discussion. What has been said will be likely to stimulate the accumulation and critical consideration of data bearing on the question.

Concerning the question of man's antiquity in terms of geological history, the discussion has for the first time sufficiently emphasized in the popular mind the importance of the most rigid scrutiny of the evidence which claims to mark a definite stage in geological history when man's existence is beyond question. For the first time, the criteria by which such evidence

must be judged, have been widely discussed. These criteria are not new to the specialists who had earlier defined and used them. But not until now had it been so clear to so large an audience that the evidence concerning man's antiquity is primarily geological, and more than this, that it involves some of the nicest and most particular questions with which geologists have to deal. R. D. S.

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THE article of Mr. Leverett in this number gives occasion to invite attention to certain errors that still linger in the literature of the glacial period, and that are occasionally supplemented by new ones of like nature. They grow out of the failure to distinguish between the Champlain depression and the earlier depression during which the main silts of the Mississippi Valley were deposited. A very large mass of evidence has been presented by different investigators under different auspices during the past decade that seems to us to have completely demonstrated a stage of elevation between the time of the main silt depositions associated with the outer tract of drift in the interior basin, and the time of the low-altitude formations of the St. Lawrence basin of which the deposits of the Champlain valley are the type. This stage of elevation embraced some of the most important events of the glacial period. The two stages of depression, we think, have thus been proved to be altogether distinct. In our judgment they were separated by a long interval of time, but it is not important to insist upon this in this connection. The evidences of this elevation between the two stages of depression embrace practically all the great glacial gravel trains of high gradient that are found south of the St. Lawrence basin. The nature and slope of these give clear testimony to the attitude of the land at the time of their formation. It is not asserted that there were not similar trains connected with the early stages of the earlier invasion of the ice, but the evidence on this point is as yet very scant. It certainly does not embrace the well-known high-gradient valley deposits of the interior, for these lie in valleys cut in the earlier drift and are connected with moraines that lie

north of it, except at those points at which the later drift reaches the border of the earlier. The moraines from which these high-gradient trains of gravel take their origin lie between the two areas of depression-deposits, and there is abundant and clear evidence that they were later than the one and earlier than the other. The phenomena connected with the earlier depression should, therefore, be considered quite independently of the Champlain depression. None of the agencies of the later depression can be legitimately appealed to in explaining the formations of the earlier depression. The confusion of the past, which is pardonable, should be eliminated, and further confusion avoided by the recognition of the distinctness of the two depressions.

T. C. C.

Analytical Abstracts of Current Literature.[1]

The Age of the Earth, by CLARENCE KING. (American Journal of Science, vol. 45, Jan. 1893, pp. 1–20, with 2 Plates).

The object of Mr. King's paper is to advance the method of determining the earth's age which was employed by Lord Kelvin (Sir William Thomson), and which was based on a consideration of its probable rate of refrigeration, by applying to it new criteria. The criteria are derived from the tidal effective rigidity of the earth, and the further argument for rigidity based upon the periodic variation of latitude, and also from the researches of Dr. Carl Barus upon the latent heat of fusion of the rock diabase, and upon its specific heats when melted and solid, and upon its volume expansion between the solid and melted state. This rock was considered to represent the probable density and composition of the surface .03 or .04 of the earth's radius.

The two principal conditions within the interior of the earth upon which physical state and all purely physical reaction of the specific materials depend, being the distribution from center to surface of pressure and heat, Mr. King points out the relative values of earth-pressures deduced from Laplace's law, and two hypothetical cases of earth-temperatures. These are expressed by a diagram which shows that the temperatures maintain an almost maximum value from within .05 of radius of the surface to the center of the earth, while pressure increases steadily throughout the entire radius. Near the surface the rate of increase of heat is greater than that of pressure, and hence its effect is to overcome the results of pressure. But this relation obtains only for earth-depths of 200 miles for an earth of the Kelvin assumption. Below this the relations are completely reversed.

The results of Barus's researches furnish the means of fixing the melting points of diabase at pressures corresponding to increasing depth within the earth. These points fall in a straight line when plotted on a chart in which the coördinate axes represent temperatures and parts of the earth's radius. By plotting on the same chart curves expressing the temperature gradients of the earth for different assumptions regarding the initial excess of heat and period of cooling, it is possible to determine the extent of the couche which must remain fused in certain cases, and also the temperature gradient at the surface of the

[1]Abstracts in this number are prepared by Joseph P. Iddings, J. A. Bownocker, Henry B. Kummel, Chas. E. Peet.

earth. From a study of these curves Mr. King is led to conclude that in order to satisfy the conditions of tidal effective rigidity there can be no considerable fused couche within the upper .06 of radius. And since for a given initial temperature the temperature gradient decreases as the period of refrigeration lengthens, an excessive period produces too low a gradient at the surface to satisfy observed rates of heat-augmentation.

To meet both these requirements Mr. King selects a gradient which falls below the diabase line of fusion, and emerges at the earth's surface at a rate not less than the mean rate of 64 ft. to 1° F. This corresponds to an initial excess of 1950° C. and a period of 24×10^6 years.

Corrections which should be made to the assumed rate of refrigeration are considered, and found to modify the result but slightly.

In comparing this method of determining the age of the earth with that by Kelvin, based on tidal retardations, King contends that, from abundant geological observation plasticity must be admitted for slow deformations, enormously in excess of the small change of figure which the stress of tidal attraction would produce but for elastic resistance. And although rigidity prevents a sudden tidal deformation of five feet, it does not prevent a slow radial deformation of five miles of the surface matter. Hence it appears that no time measure can be deduced from the supposed fixing of the present ellipticity at some past date.

A very significant comparison of the earth's age is made with that of the sun, which, according to Helmholtz and Kelvin, is 15×10^6 to 20×10^6 years. It is remarked by Newcomb that the period during which the heat received by the earth from the sun has been of a temperature which would permit water to exist in a liquid state upon the earth is probably not more than 10,000,000 years. King calls attention to the fact that all we know of the earlier strata indicates a water mechanism for their deposition, and that the evidences that life was continuous in them necessitates a climate continuously suitable for the circulation of waters. All of this period therefore must have fallen within Newcomb's limits. And the earth's age, about 24,000,000 years, accords with the 15,000,000 or 20,000,000 found for the sun. J. P. I.

The Age of the Earth. By WARREN UPHAM. (American Journal of Science, March, 1893).

Mr. Upham reviews the estimates which have been made concerning the age of the earth. These range from 10,000,000 to 14,000,000,000 years. The most reliable means, the writer argues, for estimating the age of the earth is through comparing the present rate of denudation of continental areas with the greatest determined thickness of the strata referable to the successive time divisions. He assumes the rate adopted by Wallace of a continental reduction of one foot in 3000 years. Taking Houghton's estimate

for the thickness of the stratified rocks (177,200 ft.), the time required for their formation, he finds to be 28,000,000 years. Mr. Upham next assumes the thickness of the stratified rocks to be 50 miles, and the rate of land denudation to be one foot in 6000 years. This requires 84,000,000 years for their deposition. Estimates of the relative length of geological time divisions are taken from Dana, Winchell and Davis. Estimating the time since the glacial epoch to be 8000 years, the writer concludes from Davis's ratios that from 16,000,000 to 40,000,000 years have passed since life first appeared on the globe. From changes in the floras and faunas since the beginning of the tertiary, Mr. Upham thinks the length of Cenozoic time is about 3,000,000 years. Applying this to Dana's and Winchell's ratios, he concludes that about 48,000,000 years have passed since the beginning of Cambrian time. "But," says Mr. Upham, "the diversified types of animal life in the earliest Cambrian faunas surely imply a long antecedent time for their development, on the assumption that the Creator worked before then as during the subsequent ages in the evolution of all living creatures. According to these ratios, therefore, the time needed for the deposition of the earth's stratified rocks and the unfolding of its plant and animal life must be about a hundred million years." J. A. B.

Continental Problems. Annual Address by the President, G. K. Gilbert. (Bulletin of the Geological Society of America. Vol. 4, pp. 179–190).

Two-fifths of the earth's area has a mean altitude of −14,000 feet, the plateau of the deep sea; one-fourth the continental plateau a mean altitude of +1,000 feet; the remaining third includes the intermediate slopes, the areas of extreme depth and areas of extreme height. With the exception of the Antarctic continent, the continental plateau is a continuous area, whereas the plateau of the deep sea is "separated by tracts of moderate depth into three great bodies, coinciding approximately with the Pacific, Atlantic and Indian oceans." The author discusses briefly several of the unsolved continental problems. (1) By some it is suggested that the continental form is maintained by the solidity and consequent rigidity of the earth; by others the materials underlying the continental plateau are supposed to be lighter than those beneath the oceanic plateau. The difference in density is the complement of the difference in volume. In the author's view the weight of opinion and the weight of evidence is with the latter hypothesis (the doctrine of isostacy). Accepting this doctrine, the question is (2) whether the difference in density is due to difference in temperature or difference in composition. To this question no answer can be given at present. (3) For the origin of the continents the author mentions Dana's hypothesis that the continental areas cooled first and the oceanic last. Only negative results were obtained by the

author in examining the configuration of the continental mass in order to see whether it might belt the earth in a great circle. (4) The causes of differential elevation and subsidence within the area of the continental plateau is yet unknown, but in the opinion of American geologists these differential changes of level are conclusive proof that the changes are in the lithosphere and not in the hydrosphere. (5) The doctrine of the permanence of continents is regarded as not yet fully established. (6) The growth of the continents, also, is considered as a question still open to discussion. The author does not think it is fully proved that continental growth has been as steady a process as is generally believed. Most of the evidence appealed to, and the inferences drawn therefrom, concern only the minima of ancient land. The data of unconformities, by which the maxima can alone be determined, are comparatively few, are usually difficult of determination, and therefore have never been fully assembled. Further search ought to be made along these lines before this question can be considered closed.

H. B. K.

Measurement of Geological Time. By T. MELLARD READE, C.E., F.G.S. (The Geological Magazine, March, 1893).

The particles of which the sedimentary rocks are composed have been used again and again in rock building, but were all originally derived from the pre-Cambrian rocks or from igneous rocks of later date. By estimating then the average area of the pre-Cambrian and igneous rocks, the bulk of sedimentary rocks derived from them during Cambrian and post-Cambrian times, and the rate of erosion, calculation may be made of geologic time since the beginning of the Cambrian. The author assumes "for the sake of the calculation," the average area of the pre-Cambrian and igneous rocks to be one-third the whole land area of the globe. The actual bulk of the sediments accumulated since the beginning of the Cambrian is estimated as equal to the present land area two miles thick. The average rate of erosion is taken as one foot in 3000 years. From these estimates the time that has elapsed from the beginning of the Cambrian is in round numbers 95 millions of years. When the enormous length of pre-Cambrian time is added to the above, the estimate is found to agree very closely with that of Sir Archibald Geikie, *i.e.*, 100 to 600 millions years. H. B. K.

Recent Archæological Explorations in the Valley of the Delaware. By CHAS. C. ABBOTT, M.D. (Publications of the University of Pennsylvania).

This work gives the results of the author's recent investigations in the Delaware Valley, principally at two islands near the head of tide water.

Two classes of implements were found ; those of argillite and those of jasper and quartz. He concludes that "an argillite-using man wandered far and wide over this country long before the use of jasper and quartz became so universal." The older "fairly well specialized argillite implements" are, in some localities, found in places at higher levels than the jasper and quartz implements, being deposited when the river flowed at higher levels than at present. However, by erosion and weathering, many of the argillite implements have been dislodged and mingled with the jasper implements along the course of the present river. The subject of palæolithic implements in the undisturbed Trenton gravels is not discussed. The burial customs, earth works, stone mounds, village sites and jasper quarries of the later inhabitants of the valley receive consideration. H. B. K.

The Drainage of the Bernese Jura. By AUGUST F. FOERSTE, with a *Supplementary Note on the Drainage of the Pennsylvania Appalachians.* By W. M. DAVIS. (From Proceedings of the Boston Society of Natural History, Vol. XXV, April 6, 1892, pp. 392–420, 2 plates).

The geological history of the Bernese Jura consists of a series of elevations and depressions, from the Triassic up to the time of the folding in late Tertiary time. The folds have a general east-northeast trend, and were formed by pressure exerted from the southeast along the whole line of the Jura folds. The folds are the strongest along the southeastern border, and decrease in altitude northwestward. They have been considerably eroded. Tertiary and Cretaceous strata are removed from the crests and upper flanks of the higher folds. The drainage lines are : (1) Longitudinal synclinal valleys ; (2) Occasional shallow longitudinal valleys along the crests of the anticlines, and (3) Transverse valleys across the folds. The origin of these transverse valleys, particularly those of the Suxe and the Birse, is the question especially discussed. 1. The absence of faults at the points where the valleys cross the folds is fatal to the theory of their origin through faults, as held by Thurman. 2. Their origin from fractures, as held by Studer, Jaccard, Reutimeyer and Greppin, is improbable, for the fractures are not frequent in the Jura mountains now. That every gap due to fracture should have become a transverse connecting water channel is improbable. Some would have remained as wind gaps. 3. That they did not originate from outlets of lakes, as suggested by Phillipson, and Noe and Margerie, is manifest from the fact (1) That there were lower points by which the lakes could have been drained ; (2) Some of the basins made by the folding have more than one valley cutting through the fold enclosing them. 4. The inconspicuous part played by the lateral streams on the sides of the Jura Mountains is unfavorable to the

theory of the origin of the transverse valleys through backward erosion and tapping, as suggested by Heim. Wind gaps representing the backward erosion in various stages ought to exist all over the Jura Mountains, which is contrary to fact. "This theory is particularly at fault when the strange grouping of the cross valleys along *lines* transverse to the folds is observed." 5. Their origin from superimposition is impossible, as the geological conditions required were evidently never present. 6. Mr. Foerste considers them of antecedent origin, and says: "Although the direct evidence of the progressive erosion of the streams during the rising of the folds is lacking, the systematic arrangement of several series of the transverse valleys in straight lines is strongly suggestive of the antecedent origin of the streams. This and the failure of other explanations to meet the facts are the main support of the theory."

Professor Davis notes the bearing of these conclusions on his assumption that the Appalachian streams were consequent. The consequent origin of the Jura streams was cited in support of this assumption. In view of Mr. Foerste's conclusions, Professor Davis withdraws the assumption that the "Appalachian streams were *necessarily* consequent upon the structure of the mountains when they were young," but still thinks that they *probably* were because the deformation of the Appalachians was so much stronger than that of the Jura. C. E. P.

Deep-Sea Sounding. By CAPTAIN A. S. BARKER, U.S.N. (New York: John Wiley & Sons, 133 pp. 3 maps).

This volume gives a brief account of the work done by U. S. S. Enterprise in deep-sea sounding on a cruise from Norfolk, Va., to China and return. The route taken was *via* Cape de Verde Islands, Cape of Good Hope, along the coast of South Africa, thence to Madagascar, the Comoro Islands and Zanzibar, thence across the Indian Ocean to the straits of Sunda, thence to China. Soundings were taken every 100 miles, and sometimes oftener. On the return voyage a line of soundings was made from Wellington, New Zealand to Magellan Straits, and from Montevideo northward off the east coast of South America, at varying distances, as far north as the Bermudas.

On charts accompanying the volume are recorded the depth of the soundings and data concerning the nature of the material of the sea bottom. The deepest sounding was 4,529 fathoms, made to the north of Porto Rico, the position being within forty miles of the deepest sounding (4,561 fathoms) ever taken in the Atlantic Ocean. Two submarine peaks were discovered in the South Atlantic Ocean about 20° west of Cape Town, at a depth of 731 and 979 fathoms. The materials brought up were corals, sand and shells. About 20° east north-east of Montevideo an extensive sand bank was found at a depth of 390 to 500 fathoms. The text is made up of extracts from the ship's log and the captain's private journal. C. E. P.

Observations and Experiments on the Fluctuations in the Level and Rate of Movement of Ground-water on the Wisconsin Agricultural Experiment Station Farm, and at Whitewater, Wisconsin. By FRANKLIN H. KING, Professor of Agricultural Physics, University of Wisconsin. (Washington, D. C.: U. S. Department of Agriculture, Weather Bureau, Bulletin No. 5. 75 pp. Ill., 6 plates).

This bulletin records observations made on the fluctuations of the underground water level from 1888 to July 1892. For the purpose of these observations forty-six wells, varying in depth from five feet to eighty-four feet, within an area 1,200×1,000 feet were available. There are certain short-period changes in level of the ground-water. (1) Those due to seasonal and annual changes in rainfall. (2) Seasonal and mean annual changes in soil temperature develop fluctuations by modifying the rate of percolation and of underground drainage, the changes in temperature influence the viscosity of liquids, and variations in viscosity affect the flow of water through capillary tubes of the soil. Besides these changes the surface of the ground-water level is subject to many slight oscillations, some of them almost beyond measurement. "Oscillations of atmospheric pressure of almost every character affect the under groundwater surface. The longer period barometic changes associated with cyclones, the shorter period changes which accompany thunder storms, and semi-diurnal barometric changes have their corresponding fluctuations in the ground-water." It was found that in recording the rate of flow of a tile drain, a spring and an artesian well, that all three had fluctuations synchronous with the barometric fluctuations. The magnitude of these influences is so great that Prof. King thinks the change in flow from large subterranean drainage areas can be registered upon many rivers and lakes. "The equilibrium of the water, in the capillary soil spaces above the surface of the ground-water, is so unstable that apparently the slightest cause is sufficient to upset it, causing the water to flow out of the non-capillary spaces, but only to be returned again on a moment's notice." The diurnal changes in soil temperature produce corresponding rises and falls of the water surface; "the passage of a train, even where the water is twenty feet below the surface, causes the non-capillary spaces to fill up and empty again as the weight approaches and recedes." No fluctuations due to lunar or solar tidal disturbances were observed. C. E. P.

Acknowledgments.

The following papers have been donated to the library of the Geological Department of the University of Chicago.

FROM THE PUBLISHERS.

—The Interpretation of Nature, by Nathaniel Southgate Shaler, Professor of Geology in Harvard University. Published by Houghton, Mifflin & Co., Boston and New York. 16mo. 305 pp.

—Deep-Sea Sounding, A Brief Account of the Work Done by the U. S. S. Enterprise in Deep-Sea Sounding during 1883–1886, by Captain A. S. Barker, U. S. N. Published by John Wiley & Sons, New York. 133 pp. 3 maps.

MAINLY FROM THE AUTHORS.

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(*Further acknowledgments of pamphlets already received will be made in the next issue*).

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MALASPINA GLACIER.

INTRODUCTION.

A DEFINITE classification of glaciers does not seem to be practicable, for the reason that various types which may be selected grade one into another through many intermediate forms. It is convenient, however, especially in teaching, to recognize three generic types termed Alpine, Piedmont and Continental glaciers; and a subordinate class designated as Tidewater glaciers, to include those which reach the ocean and give origin to bergs.

Alpine glaciers occur in many mountainous regions and have their type in the Alps where they were first studied. Several divisions dependent upon size have been recognized.

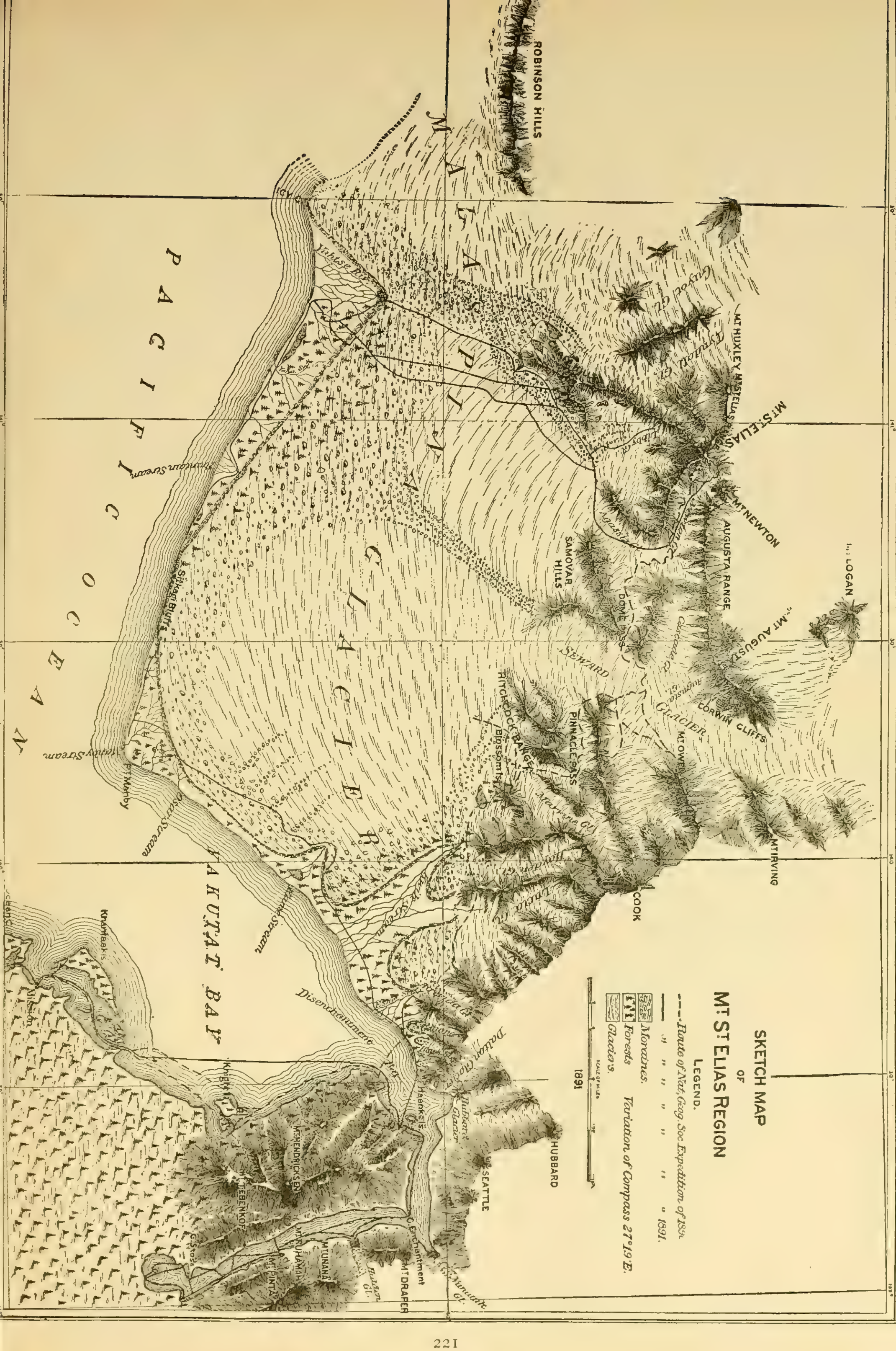
Continental glaciers as their name implies are of vast extent, and at the present time are illustrated by the ice sheets of Greenland and the Antarctic continent. The Pleistocene ice sheets of America and Europe were of this class.

Piedmont glaciers are formed on comparatively level ground at the bases of mountains where the ice is unconfined by highlands in most directions and has freedom to expand. They are fed by glaciers of the Alpine type, which spread out and unite one with another on leaving the valleys through which they descend from snow fields at higher elevations. The only known example of this class occurs in Alaska on the plain intervening between the Mt. St. Elias range and the ocean, and is the subject of this sketch.

GEOGRAPHY OF THE ST. ELIAS REGION.

The south coast of Alaska from Glacier bay on the east to the vicinity of the mouth of Copper river on the west, is bordered by a system of lofty mountains composed of many short ranges, which present steep escarpments to the south and overlook a narrow coastal-plain. At times the plain is wanting as in the vicinity of Mt. Fairweather, and the mountains rise directly from the ocean to great heights. To the north of the uplifts, facing the sea, there is an excessively rugged plateau probably about a hundred miles broad, and with a general elevation of eight or nine thousand feet. On this plateau there are hundreds of short ranges and isolated peaks rising by estimate some five or six thousand feet above the ice-filled valleys, while some of the more prominent summits have a still greater elevation. The northern border of this rugged region has been only partially explored but is known to be less precipitous than its southern face. The elevated region is destitute of both plant and animal life, and is covered with a vast névé field through which many precipitous peaks project. The southern slopes of these islands in the desert of snow are frequently bare in summer and furnish the only relief to the mantle of perpetual white. It is in this region that the ice streams supplying the Malaspina glacier have their sources.

The Tyndall glacier, shown on the accompanying map, is fed by the snow falling on the southwest portion of the Mt. St. Elias range, and flows southward with such a strong current that even after expanding on the plain at the base of the mountains and forming the western lobe of the Malaspina glacier, it continues its southward course and entering the sea forms Icy cape from which thousands of bergs are annually set adrift. Tyndall glacier has important tributaries, especially from the northern side of Robinson hills, but whether it is joined by a glacier from the elevated region to the north of the first range facing the coast, is not known. No break through which a glacier could flow has been observed in the mountain crest to be seen from the ocean, but future explorers may hope to discover such a pass.


SKETCH MAP
OF
Mt St Elias Region
Legend.
Moraines.
Forests
Glaciers.
Variation of Compass 27°19'E.
1891
ROBINSON HILLS
MALASPINA GLACIER
PACIFIC OCEAN
YAKUTAT BAY
MT ST ELIAS
MT HUXLEY
MT NEWTON
AUGUSTA RANGE
LOGAN
MT AUGUSTA
CORWIN CLIFFS
MT IRVING
COOK
HUBBARD
SEATTLE
SAMOVAR HILLS
DOME PASS
SEWARD GLACIER
HITCHCOCK RANGE
PINNACLE PASS
MT OWEN
Disenchantment Bay
Haenkels
MT TEBENKOF
MT DRAPER

The Agassiz glacier is formed by the union of many high-grade ice-streams on the eastern and northern slopes of the St. Elias range, and on the southern face of the equally precipitous Augusta range. All of these tributaries have been seen and are indicated in a rough way on the accompanying map.

Seward glacier is the principal feeder of the Malaspina ice sheet. Its most distant tributaries have their sources far to the north of the Augusta range, in the general névé field covering the main mountain mass. Scores, if not hundreds, of secondary glaciers unite to form the trunk stream which is fully three miles broad where best defined, and probably not less than sixty or seventy-five miles long.

Besides the great glaciers enumerated above there are several smaller ice-streams of the same type, such as the Marvine, Hitchcock, Lucia, etc., each of which is eight or ten miles in length and flows through a deep well-defined valley. Between these various trunk streams there are scores of high-grade glaciers that originate in deep cirques in the southern face of the mountains or in some instances, on the rugged slopes themselves where there are no depressions, and descend to and merge with the vast plateau of ice skirting the ocean.

Before giving special attention to the Malaspina glacier it may be well to glance at a few other geographical conditions which influence its existence.

The climate of southern Alaska adjacent to the coast is mild and uniform. The summers are cool with much fog and rain; the winters are not severe, but clear days are rare and snow falls to the depth of several feet. Among the neighboring mountains the snow-fall is excessive and occurs during every month of the year. In the névé region near Mt. St. Elias at an elevation of about 5,000 ft. it is not uncommon to see strata of compact snow without a parting, fifty feet thick exposed in the walls of crevasses. The mean annual temperature on the coast is thought to be about 40-45 deg. F., but this estimate is based on observation at a very limited number of stations. The humidity is excessive, and the mean annual rain-fall

is known to be about an hundred inches. In the vicinity of Mt. St. Elias it is probably even greater than this. The prevailing winds are from the south, at least in summer, and are laden with moisture which is precipitated when the mountains are reached. To the north of the mountains the climate is far different from what it is on the coast. The summers are short and hot and the winters marked by extreme severity; the rainfall is small throughout the year and perennial snow is not seen even on mountains four or five thousand feet high and situated near and even north of the Arctic Circle.

On the mountains facing the ocean the winter snow extends down to sea level but melts during spring and summer so as to form a well defined boundary, or "snow line," which recedes from the coast as the warm season advances. In August and September it has an elevation of about 2,500 feet, corresponding on the glaciers with the lower limit of the névés. The regions below and above the snow line are in marked contrast. From the ocean up to an elevation of from 2,500 to 3,000 feet in summer, every island in the ice as well as the low lands along the coast and even the moraines on the lower border of the Piedmont ice-sheet, are covered with luxuriant vegetation, and are frequently brilliant with banks of flowers. Above the snow line except on occasional sunny slopes at comparatively low elevation, where Alpine flowers thrive, all is desolate, lifeless winter. The well known features characteristic of glacial ice and névé snow are sharply defined by the same horizon. In the higher mountains snow storms are frequent even in summer, and at elevations exceeding about 13,000 feet rain never falls and the snow is fine and dry. On the mountain tops the snow does not soften, even on hot summer days. Its indefinite accumulation is prevented by avalanches and by its being blown away.

The relief of the St. Elias region is due largely to displacements. The mountains are in many instances formed of tilted blocks bounded by faults, and the prevailing structure approaches the Great Basin type. The effects of pre-glacial stream erosion are not distinguishable and in many instances the ice drainage is

consequent upon the prevailing structure. This is shown principally by the fact that large glaciers, such as the Agassiz and Seward, follow lines of displacement; in several instances, cascades occur where glaciers cross faults.

THE PIEDMONT ICE SHEET.[1]

Area.—The Malaspina glacier extends with unbroken continuity from Yakutat bay 70 miles westward, and has an average breadth of between 20 and 25 miles. Its area is approximately 1,500 square miles; or intermediate in extent between the area of the State of Rhode Island and the area of the State of Delaware.

It is a vast, nearly horizontal plateau of ice. The general elevation of its surface at a distance of five or six miles from its outer border is about 1,500 feet. The central portion is free from moraines or dirt of any kind, but is rough and broken by thousands and tens of thousands of crevasses. Its surface, when not concealed by moraines, is broadly undulating, and recalls the appearance of the rolling prairie lands west of the Mississippi. From the higher swells on its surface one may see for many miles in all directions without observing a single object to break the monotony of the frozen plain. So vast is the glacier that, on looking down on it from elevations of two or three thousand feet above its surface, its limits are beyond the reach of vision.

Lobes.—The glacier consists of three principal lobes, each of which is practically the expansion of a large tributary ice stream. The largest has an eastward flow, toward Yakutat bay, and is supplied mainly by the Seward glacier. The next lobe to the west, is the expanded terminus of the Agassiz glacier; its current is toward the southwest. The third great lobe lies between the Chaix and Robinson hills, and its main supply of ice is from the Tyndall and Guyot glaciers. Its central current is south-

[1] This account of the Malaspina glacier has been compiled principally from the proof-sheets of a report by the writer on a second expedition to Mt. St. Elias in 1891, to appear in the Thirteenth Ann. Rep. of the U. S. Geological Survey.

ward. The direction of flow in the several lobes explains the distribution of the moraines about their borders.

The Seward lobe melts away before reaching Yakutat bay and ends with a low frontal slope, but its southern margin has been eaten into by the ocean, so as to form the Sitkagi bluffs. The Agassiz lobe is complete, and is fringed all about its outer border by broad moraines. The Guyot lobe pushes boldly out into the ocean, and breaking off forms magnificent ice cliffs.

Characteristics of the non-moraine-covered surface.—On the north border of the glacier, but below the line of perpetual snow, where the great plateau of ice has a gentle slope, the surface melting gives origin to hundreds of rills and rivulets which course along in channels of clear ice until they meet a crevasse or moulin and plunge down into the body of the glacier to join the drainage beneath. On warm summer days when the sun is well above the horizon the murmur of streams may be heard wherever the ice surface is inclined and not greatly broken, but as soon as the shadows of evening cross the ice fields melting ceases and the silence is unbroken. These streams are always of clear, sparkling water, and it is seldom that their channels contain debris. Where the surface of the glacier is nearly level, and especially when broken by crevasses, surface streams are absent, although the clefts in the ice are frequently filled with water. The moulins in which the larger of the surface streams usually disappear are well-like holes of great depth. They are seldom straight, however, as the water in plunging into them usually strikes the opposite side and causes it to melt away more rapidly than the adjacent surfaces. The water in descending is dashed from side to side and increases their irregularities. A deep roar coming from the hidden chambers to which the moulins lead frequently tells that large bodies of water are rushing along the ice caves beneath. In the southern portion of the glacier, where the ice has been deeply melted, and especially where large crevasses occur, the abandoned tunnels made by englacial streams are sometimes revealed. These tunnels are frequently 10 or 15 feet high, and occasionally one may pass

through them from one depression in the glacier to another. In some instances they are floored with debris, some of which is partially rounded. As melting progresses this material is concentrated at the surface as a moraine.

The ice in the various portions of the glacier was observed to be formed of alternate blue and white bands, as is the rule in glacial ice generally. The blue bands are of compact ice, while the white bands are composed of ice filled with air cavities. The banded structure is usually nearly vertical, but the dip, when noticeable, is northward. Nearly parallel with the blue and white layers, but crossing them at low angles, there are frequently bands of hard, blue ice several hundred feet long and 2 or 3 inches in thickness which have a secondary origin, and are due to the freezing of waters in fissures.

The rapid melting of the surface produces many curious phenomena, which are not peculiar to this glacier, however, but common to many ice bodies below the line of perpetual snow. The long belts of stone and dirt forming the moraines protect the ice beneath from the action of the sun and air, while adjacent surfaces waste away. The result of this differential melting is that the moraines become elevated on ridges of ice. The forms of the ridges vary according to the amount and character of the debris resting upon them. In places they are steep and narrow, and perhaps 150 or 200 feet high. From a little distance they look like solid masses of debris, and resemble great railroad embankments, but on closer examination they are seen to be ridges of ice, covered with a thin sheet of earth and stones. The sides of such ridges are exceedingly difficult to climb, owing to the looseness of the stones, which slide from beneath one's feet and roll down the slopes. The larger bowlders are the first to be dislodged by the melting of the ice, and, rolling down the sides of the ridges, form a belt of coarse debris along their margins. In this way a marked assortment of the debris in reference to size and shape frequently takes place. In time the narrow belts of large bowlders become elevated in their turn and form the crests of secondary ridges. Rocks rolling down the steep slopes are

broken into finer and finer fragments and are reduced in part to the condition of sand and clay. When the debris is sufficiently comminuted it is sometimes carried away by surface streams and washed into crevasses and moulins. Not all of the turbidity of the subglacial streams can be charged to the grinding of the glacier over the rocks on which it rests, as a limited portion of it certainly comes from the crushing of the surface moraines during their frequent changes of position.

Isolated blocks of stone lying on the glacier, when of sufficient size not to be warmed through by the sun's heat in a single day, also protect the ice beneath and retain their position as the adjacent surface melts, so as to rest on pedestals frequently several feet high. These elevated blocks are usually flat, angular masses, sometimes 20 feet or more in diameter. Owing to the greater effect of the sun on the southern side of the columns which support them, the tables are frequently inclined southward, and ultimately slide off their pedestals in that direction. No sooner has a block fallen from its support, however, than the process is again initiated, and it is again left in relief as the adjacent surface melts. The many falls which the larger blocks receive in this manner cause them to become broken, thus illus trating another phase of the process of comminution to which sur face moraines are subjected. On Malaspina glacier the formation of glacial tables is confined to the summer season. In winter the surface of the glacier is snow-covered and differential melting can not be marked. The fact that glacial tables are seldom seen just after the snows of winter disappear suggest that winter melting takes place to some extent, but in a different manner from what it does in the summer. Just how the blocks are dislodged from the pedestals in winter has not been observed.

While large objects lying on the surface of the glacier are elevated on pedestals in the manner just described, smaller ones, as is well known and especially those of dark color, become heated by the sun, and, melting the ice beneath, sink into it. When small stones and dirt are gathered in depressions on the surface of the glacier, or, on a large scale, when moulins

become filled with fine debris and the adjacent surface is lowered by melting, the material thus concentrated acts as do large bowlders, and protects the ice beneath. But as the gravel rises in reference to the adjacent surface, the outer portion rolls down from the pedestal on all sides, and the result is that a sharp cone of ice is formed, having a sheet of gravel and dirt over its surface. These sand cones, as they are called, sometimes attain a height of ten or twelve feet, and form conspicuous and characteristic features of the glaciers over large areas.

The surface of Malaspina glacier over many square miles, where free from moraine, is covered with a coral-like crust which results from the alternate melting and freezing of the surface. The crevasses in this portion of the vast plateau are seldom of large size, and, owing to the melting of their margins, are broad at the surface and contract rapidly downward. They are in fact mere gashes, sometimes ten or twenty feet deep, and are apparently the remnants of larger crevasses formed in the glaciers which flow down from the mountains. Deeper crevasses occur at certain localities about the border of the glacier, where the ice at the margin falls away from the main mass, but these are seldom conspicuous, as the ice in the region where they occur is always heavily covered with debris and the openings become filled with stones and bowlders. The generally level surface of the glacier and the absence of large crevasses indicate that the ground on which it rests is comparatively even. Where the larger of the tributary glaciers join it, however, ice falls occur, caused by steep descents in the ground beneath. These falls are just at the lower limit of perpetual snow and are only fully revealed when melting has reached its maximum and the snows of the winter have not yet begun to accumulate.

Moraines.—From any commanding station overlooking Malaspina glacier one sees that the great central area of clear, white ice is bordered on the south by a broad, dark band formed by bowlders and stones. Outside of this and forming a belt concentric with it is a forest-covered area, in many places four or five miles wide. The forest grows on the moraine, which rests

upon the ice of the glacier. In a general view by far the greater part of the surface of the glacier is seen to be formed of clear ice, but in crossing it one comes first to the forest and moraine-covered border, which, owing to the great obstacles it presents to travel, impresses one as being more extensive than it is in reality.

The moraines not only cover all of the outer border of the glacier, but stream off from the mountain spurs projecting into it on the north. As indicated on the accompanying map, one of these trains starting from a spur of the Samovar hills crosses the entire breadth of the glacier and joins the marginal moraine on its southern border. This long train of stones and bowlders is really a highly compound medial moraine formed at the junction of the expanded extremities of the Seward and Agassiz glaciers.

All of the glaciers which feed the great Piedmont ice-sheet are above the snow line, and the debris they carry only appears at the surface after the ice descends to the region where the annual waste is in excess of the annual supply. The stones and dirt previously contained in the glacier are then concentrated at the surface owing to the melting of the ice. This is the history of all of the moraines on the glacier. They are formed of the debris brought out of the mountains by the tributary Alpine glacier, and concentrated at the surface by reason of the melting of the ice.

Malaspina glacier in retreating has left irregular hillocks of coarse debris which are now densely forest-covered. These deposits do not form a continuous terminal moraine, however, but a series of irregular ridges and hills having a somewhat common trend. They indicate a slow general retreat without prolonged halts. The heaps of debris left as the ice front retreated have a general parallelism with the present margin of the glacier and are pitted with lake basins, but only their higher portions are exposed above the general sheet of sand and gravel spread out by streams draining the glacier.

The blocks of stone forming the moraines now resting on the

ice are of all sizes up to twenty or thirty feet in diameter, but those of large dimensions are not common. The stones are rough and angular except when composed of material like granite, which on weathering forms oval and rounded boulders of disintegration. So far as has been observed, very few of the stones on the glacier have polished or striated surfaces. The material of which the moraines are composed is of many kinds, but individual ridges frequently consist of fragments of the same variety of rock, the special kind in each case depending on the source of the thread in the great ice current which brought the fragments from the mountains.

In many instances, particularly near the outer border of the ice sheet, there are large quantities of tenacious clay, filled with angular stones, which is so soft, especially during heavy rains, that one may sink waist deep in the treacherous mass. Sometimes blocks of stone a foot or more square float on the liquid mud and lure the unwary traveler to disaster.

On the eastern margin of the ice sheet adjacent to Yakutat bay, where the frontal slope is low, there are broad deposits of sand and well rounded gravel which has been spread out over the ice. On the extreme margin of the glacier this deposit merges with hillocks and irregular knolls of the same kind of material, some of which rise a hundred feet above the nearest exposure of ice and are clothed with dense forests. The debris is so abundant and the ice ends in such a low slope that it is frequently impossible to determine where the glacier actually terminates. The water-worn material here referred to as resting on the glacier, has been brought out of tunnels in the ice, as will be noticed further on.

Surface of the fringing moraines.—A peculiar and interesting feature of the moraine on the stagnant border of Malaspina glacier is furnished by the lakelets that occur everywhere upon it. These are found in great numbers both in the forest-covered moraine and in the outer border of the barren moraine. They are usually rudely circular, and have steep walls of dirty ice which slope toward the water at high angles, but are undercut at the

bottom, so that the basins in vertical cross section have something of an hour-glass form. The walls are frequently from 50 to 100 feet high, with a slope of 40° to 50°, and sometimes are nearly perpendicular. Near the water's edge the banks are undercut so as to leave a ridge projecting over the water. The upper edge of the walls is formed of the sheet of debris which covers the glacier, and the melting of the ice beneath causes this material to roll and slide down the ice slopes and plunge into the waters below. The lakes are usually less than 100 feet in diameter, but larger ones are by no means uncommon, several being observed which were 150 or 200 yards across. Their waters are always turbid owing to the mud which is carried into them by small avalanches and by the rills that trickle from their sides. The rattle of stones falling into them is frequently heard while traveling over the glacier, and is especially noticeable on warm days, when the ice is melting rapidly, but is even more marked during heavy rains. The crater-like walls inclosing the lakes are seldom of uniform height, but frequently rise into pinnacles. Between the pinnacles there are occasionally low saddles, through which in some instances the lakes overflow. Frequently there are two low saddles nearly opposite to each other, which suggests that the lakes were formed by the widening of crevasses. The stones and dirt which fall into them, owing to the melting of the walls, gradually fill their bottoms. Instances are numerous where the waters have escaped through crevasses or openings in the bottom of the basin, leaving an exceedingly rough depression, with a heavy deposit of debris at the bottom.

As the general surface of the glacier is lowered by melting, the partially filled holes gradually disappear and their floors, owing to the deep accumulation of debris on them, which protects the ice from melting, become elevated above the surrounding surface, in the same manner that glacial tables are formed. The debris covering these elevations slides down their sides as melting progresses, and finally a rugged pyramid of ice, covered with a thin coating of debris, occupies the place of the

former lake. These pyramids frequently have a height of 60 or 80 feet, and are sometimes nearly conical in shape. They resemble "sand cones," but are of much greater size and are sheathed with coarser debris. The sand cones are usually, if not always, formed and melted away during a single season, while the debris pyramids require several seasons for their cycle of change.

Like the lakelets to which they owe their origin, the debris pyramids are confined to the stagnant portions of the glacier and play an important part in the breaking up and comminution of the material forming the marginal moraines. Owing to the sliding of the bowlders and stones into the lakelets and their subsequent fall from the sides of the pyramids, they are broken and crushed so that the outer portion of the glacier, where the process has been going on longest, is covered with finer debris and contains more clay and sand than the inner portions.

Just how the holes containing glacial lakelets originate it is difficult to say, but their formation seems to be initiated, as already suggested, by the melting back of the sides of crevasses. Breaks in the general sheet of debris covering the glacier expose the ice beneath to the action of the sun and rain, which causes it to melt and the crevasses to broaden. The openings become partially filled with water and lakelets are formed. The waves wash the debris from the ice about the margin of the lakelets, thus exposing it to the direct attack of the water, which melts it more rapidly than higher portions of the slopes are melted by the sun and rain. It is in this manner that the characteristic hourglass form of the basins originates. The lakelets are confined to the outer or stagnant portion of the glacier, for the reason that motion in the ice would produce crevasses through which the water would escape. Where glacial lakelets occur in great numbers it is evident that the ice must be nearly or quite stationary, otherwise the basins could not exist for a series of years. The lakelets and the pyramids resulting from them are the most characteristic features of the outer border of the glacier. The number of each must be many thousand. They occur not only in the outer portion of the barren moraine, but also throughout

the forest-covered area still nearer the outer margin of the glacier. Large quantities of trees and bushes fall into them with the debris that slides from their sides, and tree trunks, roots and soil, thus become buried in the moraines.

Forests on the moraines.—The outer and consequently older portions of the fringing moraines are covered with vegetation, which in places, particularly near the outer margin of the belt, has all the characteristics of old forests. It consists principally of spruce, alder and cottonwood trees, and a great variety of shrubs, bushes and ferns. In many places the ice beneath the dense forest is not less than a thousand feet thick. The vegetation is confined principally to the border of the Seward lobe. Near Yahtse river the belt is 5 miles broad, but decreases toward the east, and is absent at the Sitkagi bluffs, where the glacier is being eaten away by the sea. It is only on the stagnant borders of the ice sheet that forests occur. Both glacial lakelets and forests on the moraines are absent where the ice has motion. The forest-covered portion is by estimate between 20 and 25 square miles in area.

Outer margin.—The southern margin of Malaspina glacier, between the Yahtse and Point Manby, is abrupt and forms a bluff that varies in height from 140 to 300 feet or more. The bluff is so steep in most places and is so heavily incumbered with fallen trees and boulders, that it is with difficulty one can climb it. Many times the trouble in ascending is increased by land slides which have piled the superficial material in confused heaps, and in other instances the melting of the ice beneath the vegetation has left concealed pit-falls into which one may drop without warning. The bluff formed by the margin of the glacier when not washed by the sea, is boldest and steepest where the covering of vegetation is most dense. Where the covering consists of stones and dirt without vegetation, however, the margin may still be bold. This is illustrated between the mouth of the Yahtse and Icy cape, where the ice is concealed beneath a general sheet of debris, but has a bold convex margin which rises abruptly from the desolate torrent-swept waste at its base.

When the glacier meets the sea the ice is cut away at the water-level, and blocks fall from above, leaving perpendicular cliffs of clear ice. At Icy cape there is a bold headland of this nature from which bergs are continually falling with a thunderous roar that may be heard fully twenty miles away. On the crest of the cliffs of clear blue ice there is a dark band formed by the edge of the sheet of debris covering the glacier, and showing that the moraine which blackens its surface along its outer margin is entirely superficial. At Sitkagi bluffs the glacier is again washed by the sea but the base of the ice is there just above the water-level and recession is slow. The bluffs are heavily covered with stones and dirt, and icebergs do not form.

At the heads of the gorges in the margin of the glacier leading to the mouths of tunnels, the dirt-covered ice forms bold cliffs which are most precipitous at the heads of the reëntrant angles. The eastern margin of the ice sheet, facing Yakutat bay, is low and covered to a large extent with water-worn debris. The ridges on the glacier formed by moraines are there at right angles to the margin of the ice and are bare of vegetation. The reason for the exceptionally low slope of the eastern margin of the ice sheet seems to be that the current in the ice is there eastward and the glacier is melting back without leaving a stagnant border.

Marginal lakes. — The water bodies here referred to are called "marginal lakes" for the reason that they are peculiar to the margins of glaciers. Where rocks border an ice field or project through it they become heated, especially on southern exposures, and, radiating heat to the adjacent ice, cause it to melt. A depression is thus formed along the margin of the ice, which becomes a line of drainage. Water flowing through such a channel accelerates the melting of the ice, at least until a heavy coating of debris has accumulated. When a steep mountain spur projects into an ice field the lines of drainage on each side converge and frequently unite at its extremity, forming a lake, from which the water usually escapes through a tunnel in the ice. Typical instances of lakes of this character occur at Terrace point, at the

south end of the Hitchcock range, and again about the base of the Chaix hills.

When a stream flows along the side of a glacier a movement in the ice or the sliding of stone and dirt from its surface sometimes obstructs the drainage and causes the formation of another variety of marginal lakes. In such instances the imprisoned waters usually rise until they can find an outlet across the barrier and then cut a channel through it.

A glacier in flowing past the base of a mountain frequently obstructs the drainage of lateral valleys and causes lakes to form. These usually find outlets, as in the case of lakes at the end of mountain spurs, through a subglacial or englacial tunnel, and are filled or emptied according as the tunnel through which the waters escape affords free drainage or is obstructed. Several examples of this variety of marginal lakes occur on the west and north sides of the Chaix hills. They correspond in the mode of their formation with the well-known Merjelen See of Switzerland.

Other variations in the manner in which glaciers obstruct drainage might be enumerated, but those mentioned cover all of the examples thus far observed about Malaspina glacier. The conditions which lead to the formation of the marginal lakes are unstable, and the records which the lakes leave in the form of terraces, deltas, etc., are consequently irregular. When streams empty into one of these lakes, deltas and horizontally stratified lake beds are formed, as in ordinary water bodies, but as the lakes are subject to many fluctuations, the elevations at which the records are made are continually changing, and in instances like those about Malaspina glacier, where the retaining ice body is constantly diminishing, may occupy a wide vertical interval.

Drainage begins on the southeast side of Chaix hills at Moore's Nunatak, where during the time of our visit there were two small lakes, walled in on nearly all sides by the moraine covered ice of Malaspina glacier. The water filling these basins comes principally from the high ice fall at the north, where the glacier descends over a projecting spur running east from

Moore's Nunatak. The water escaped from the first lake across a confused mass of debris which had slid from the ice bluff bordering the stream and formed a temporary dam. Below the dam the water soon disappeared beneath deeply crevassed and heavily moraine-covered ice and came to light once more at the mouth of a tunnel about a mile to the southwest. The second lake, at the time of our visit, had almost disappeared, but its former extent was plainly marked by a barren sand flat many acres in extent, and by terraces along its western border. The lake occupied a small embayment in the hills, the outlet of which had been closed by the ice flowing past it. Below the second lake the stream flows along the base of densely wooded knolls and has a steep moraine-covered bluff of ice for its left bank. About a mile below it turns a sharp projection of rocks and cuts deeply into its left bank, which stands as an overhanging bluff of dirty ice over 100 feet high. The stream then flows nearly due west for some 3 miles to Crater lake. On its right bank is a terrace about 150 feet high which skirts the base of the Chaix hills and marks the position of the stream at a former stage. The terrace is about 100 yards broad, and above it are two other terraces on the mountain slope, one at an elevation of 50 feet and the other at 75 feet above the broad terrace. The upper terraces were only observed at one locality, and were probably due to deposits formed in a marginal lake at the end of a mountain spur.

The terraces left by streams flowing between a moraine-covered glacier and a precipitous mountain slope are peculiar and readily distinguishable from other similar topographic features. The channels become filled principally with debris which slides down the bank of ice. This material is angular and unassorted, but when it is brought within the reach of flowing waters soon becomes rounded and worn. On the margin of the channel, adjacent to the glacier, there is usually a heavy deposit of unassorted debris which rests partly upon the ice and forms the actual border of the stream. When the glacier is lowered by melting, the steam abandons its former channel and repeats

the process of terrace building at a lower level. The material forming the terrace at the base of Chaix hills is largely composed of blue clay filled with both angular and rounded stones and bowlders, but its elevated border is almost entirely of angular debris. The drainage from the mountain slope above the terrace is obstructed by the elevated border referred to, and swamps and lagoons have formed back of it. In the material forming the terraces there are many tree trunks, and growing upon its surface there is a forest of large spruce trees.

At the extreme southern end of the Chaix hills the drainage from the northeast, which we have been tracing, joins another stream from the northwest and forms Lake Castani. This lake, like the one at Terrace point, is at the south end of a precipitous mountain ridge projecting into the glacier and drains through a tunnel in the ice. The stream flowing from it is known as the Yahtse and flows for six or eight miles beneath the ice before emerging at its southern margin. Large quantities of both coarse and fine material are being carried into Lake Castani by tributary streams and is there deposited as deltas and lake beds. When the lake is drained, as sometimes happens, vast quantities of this material must be carried into the tunnel through which the waters escape.

On the west side of Chaix hills are several other marginal lakes of the same general character as those just described. The one next northwest of Lake Castani occupies a long narrow valley between two outstanding mountain ridges, and is retained by the glacier which blocks the end of the recess thus formed. This lake was clear of ice July, 1891, and of a dark blue color, showing that it received little drainage from the glacier. Other lakes on the northwest side of the Chaix hills are of a similar nature, and during my visit were heavily blocked with floating ice. On the north side of Chaix hills there are other small water bodies occupying embayments and retained by the glacier which flows past their entrances. The water from all these lakes escapes through tunnels.

The lakes to which attention has been directed are especially

interesting, as they illustrate one phase of deposition depending upon glaciation, and suggest that a great ice sheet like that which formerly covered New England very likely gave origin to marginal lakes, the records of which should be found on steep mountain slopes.

Drainage.—The drainage of the Malaspina glacier is essentially englacial or subglacial. There is no surface drainage excepting in a few localities, principally on its northern border, where there is a slight surface slope, but even in such places the streams are short and soon plunge into a crevasse or a moulin and join the drainage beneath.

On the lower portions of the Alpine glaciers, tributary to the main ice-sheet, there are sometimes small streams coursing along in ice channels, but these are short lived. On the borders of the tributary glaciers there are frequently important streams flowing between the ice and the adjacent mountain slope, but when these come down to the Malaspina glacier they flow into tunnels and are lost to view.

Along the southern margin of the glacier, between the Yahtse and Point Manby, there are hundreds of streams which pour out of the escarpment formed by the border of the glacier, or rise like great fountains from the gravel and bowlders accumulated at its base. All of these are brown and heavy with sediment and overloaded with bowlders and stones. The largest and most remarkable of these springs is the one indicated on the accompanying map as Fountain stream. This comes to the surface through a rudely circular opening, nearly 100 feet in diameter, surrounded in part by ice. Owing to the pressure to which the waters are subjected they boil up violently, and are thrown into the air to the height of 12 to 15 feet, and send jets of spray several feet higher. The waters are brown with sediment, and rush seaward with great rapidity, forming a roaring stream, fully 200 feet broad, which soon divides into many branches, and is spreading a sheet of gravel and sand right and left into the adjacent forest. Where Fountain stream rises, the face of the glacier is steep and covered with huge bowlders, many of which are too

large for the waters to move. The finer material has been washed away, however, and a slight recession in the face of the ice bluff has resulted. The largest stream draining the glacier is the Yahtse. This river, as already stated, rises in two principal branches at the base of the Chaix hills, and flowing through a tunnel some six or eight miles long, emerges at the border of the glacier as a swift brown flood fully one hundred feet across and fifteen or twenty feet deep. The stream, after its subglacial course, spreads out into many branches, and is building up an alluvial fan which has invaded and buried several hundred acres of forest.

In traversing the coast from the Yahtse to Yakutat bay, we crossed a large number of streams which drain the ice fields of the north, some of which were large enough to be classed as rivers. When the streams on flowing away from the glacier are large they divide into many branches, as do the Yahtse and Fountain, and enter the sea by several mouths. When the streams are small, however, they usually unite to form large rivers before entering the ocean. The Yahtse and Fountain, as we have seen, are examples of the first, while Manby and Yahna streams are examples of the second class. Manby stream rises in hundreds of small springs along the margin of the glacier which flow across a desolate torrent-swept area and unite just before reaching the ocean into one broad, swift flood of muddy water much too deep for one to wade.

On the border of the glacier facing Yakutat Bay, however, the drainage is different. The flow of the ice is there eastward, although the margin is probably stagnant, and instead of forming a bold, continuous escarpment, ends irregularly and with a low frontal slope. The principal streams on the eastern margin in 1891 were the Osar, Kame and Kwik. Each of these issues from a tunnel and flows for some distance between walls of ice. Of the three streams mentioned the most interesting is the Kame, which issues as a swift brown flood partially choked with broken ice, from the mouth of a tunnel and flows for half a mile in an open cut between precipitous walls of dirty ice 80 to 100

feet high. This is the longest open drainage channel that I have yet seen in the ice. It is about 50 feet broad where the stream rushes from the glacier, but soon widens to several times this breadth. Its bottom is covered with rounded gravel and sand, and along its sides are sand-flats and terraces of gravel resting upon ice. The swift, muddy current was dotted with small bergs stranded here and there in the center of the stream, showing that the water was shallow. Evidently the stream has a long subglacial course and carries with it large quantities of stones which are rounded as in ordinary rivers. Gravel and sand are being rapidly deposited in the ice channel through which it flows after emerging from its tunnel. Broad sand-flats are being spread out in the lakes and swamps two or three miles to the east. The stream is some four or five miles in length and near Yakutat bay meanders over a barren area perhaps a mile broad. I have called it Kame stream because of a ridge of gravel running parallel with it which was deposited during a former stage when the waters flowed about 100 feet higher than now and deposited a long ridge of gravel on the ice which has all the characteristics of the kames in New England. In the more definite classification of glacial sediments now adopted, this would more properly be called an osar.

Near the shore of Yakutat bay the streams from the glacier spread out in lagoons and sand-flats, where much of the finer portion of the material they carry is deposited. Sometimes this debris is spread out above the ice, and forms level terraces of fine sand and mud which become prominent as the glacier wastes away.

Osars.—The drainage of the glacier has not been investigated as fully as its importance demands, but the observations already made seem to warrant certain conclusions in reference to deposits made within the glacier by subglacial or englacial streams.

When the streams from the north reach the glacier they invariably flow into tunnels and disappear from view. The

entrances to the tunnels are frequently high arches, and the streams flowing into them carry along great quantities of gravel and sand. About the southern and eastern borders of the glacier, where the streams emerge, the arches of the tunnels are low, owing principally to the accumulation of debris which obstructs their discharge. In some instances, as at the head of Fountain stream, the accumulation of debris is so great that the water rises through a vertical shaft in order to reach the surface, and rushes upward under great pressure. The streams flowing from the glacier bring out large quantities of well rounded sand and gravel, much of which is immediately deposited in alluvial cones. This much of the work of subglacial streams is open to view and enables one to infer what takes place within the tunnels and to analyze to some extent the processes of subglacial deposition.

The streams issuing from the ice are overloaded, and, besides, on emerging, frequently receive large quantities of coarse debris from the adjacent moraine-covered ice cliffs. The streams at once deposit the coarser portion of their loads, thus building up their channels and obstructing the outlets of the tunnels. The blocking of the tunnels must cause the subglacial streams to lose force and deposit sand and gravel on the bottom of their channels ; this causes the water to flow at higher levels, and coming in contact with the roofs of the tunnels, enlarges them upwards ; this in turn gives room for additional deposits within the ice as the alluvial cones at the extremities of the tunnels grow in height. In this way narrow ridges of gravel and sand, having perhaps some stratification due to periodic variations in the volume of the streams, may be formed within the ice. When the glacier melts, the gravel ridges contained within it will be exposed at the surface, and as the supporting walls melt away, the gravel at the top of the ridge will tend to slide down so as to give the deposit a pseudo-anticlinal structure. Ridges of gravel deposited in tunnels beneath the moraine-covered portion of the Malaspina glacier, would have bowlders dropped upon them as the ice melts, but where the glacier is free

from surface debris there would be no angular material left upon the ridges when the ice finally disappeared. Such a system of deposition as is sketched above would result in the formation of narrow, winding ridges of cross-bedded sand and gravel, corresponding, seemingly, in every way to the osars of many glaciated regions. The process of subglacial deposition pertains especially to stagnant ice sheets of the Malaspina type, which are wasting away. In an advancing glacier it is evident that the conditions would be different, and subglacial erosion might take place instead of subglacial deposition.

Alluvial cones.—Below the outlets of the tunnels through which Malaspina glacier is drained, there are immense deposits of bowlders, gravel, sand, and mud which have the form of segments of low cones. These deposits are of the nature of the "alluvial cones," or "alluvial fans" so common at the bases of mountains in arid regions, and are also related to the "cones of dejection," deposited by torrents, and to the subaërial portion of the deltas of swift streams. As deposits of this nature have not been satisfactorily classified, I shall for the present call them "alluvial cones."

As stated in speaking of osars, the streams issuing from tunnels in Malaspina glacier at once begin to deposit. The larger bowlders and stones are first dropped, while gravel, sand and silt are carried farther and deposited in the order of their coarseness. The deposits originating in this way have a conical form, the apex of each cone being at the mouth of a tunnel. As the apexes of the cones are raised by the deposition of coarse material, their peripheries expand in all directions, and as the region is densely forest covered, great quantities of trees become buried beneath them. As the ice at the head of an alluvial cone recedes, the alluvial deposit follows it by deposition on the upstream side. The growth of the alluvial cones will continue so long as the glacier continues to retreat, or until the streams which flow over them have their subglacial courses changed. The material of the alluvial cones is as heterogeneous as the material forming the moraines on the border of the glacier, about which

they form, but the greater and practically the entire accumulation is more or less rounded and waterworn. Cross stratification characterizes the deposits throughout, and on the surface of many of the cones, and probably in their interior, also, there are large quantities of broken tree trunks and branches. The coarse deposits first laid down on a growing alluvial cone are buried beneath later deposits of finer material in such a way that a somewhat regular stratification may result. A deep section of one of these deposits should show a gradual change from fine material at the top to coarse stones and subangular bowlders at the bottom. Their outer borders are of fine sand and mud, and when the distance of the ocean is sufficient, the streams flowing from them deposit large quantities of silt on their flood plains. The very finest of the glacial mud is delivered to the ocean and discolors its water for many miles from land.

The formation of alluvial cones about the border of a stagnant ice sheet, and the deposition of ridges of gravel within it, have an intimate connection and are in fact but phases of a single process. The growth of an alluvial cone tends to obstruct the mouth of the tunnel through which its feeding stream discharges; this causes the stream to deposit within the tunnel ; this, again, raises the stream and allows it to build its alluvial cone still higher. In the case of Malaspina glacier where this process has been observed, the ice sheet is stagnant, at least on its border, and is retreating. The ground on which it rests is low, but is thought to be slightly higher on the southern margin of the glacier than under its central portion. The best development of alluvial cones and osars would be expected in a stagnant ice sheet resting on a gently inclined surface, with high lands on the upper border from which abundant debris could be derived. These ideal conditions are nearly reached in the example described.

Glacial and ocean records.—Much has been written concerning the character of the deposits made by glaciers when they meet the ocean, but so far as can be judged from the conditions observed about the borders of Malaspina ice sheet, the sea

is much more powerful than the ice. Where the two unite their action, the sea leaves the more conspicuous records. The waters are active and aggressive, while the glacier is passive. Where the glacier enters the ocean its records are at once modified and to a great extent obliterated. The presence of large bowlders in marine sediments, or in gravels and sands along the coast is about all the evidence of glacial action that can be expected under the conditions referred to. Where the swift streams from the Malaspina glacier enter the ocean the supremacy of the waves, tides, and currents is even more marked. The streams are immediately turned aside by the accumulation of sand bars across their mouths, and nothing of the nature of stream-worn channels beneath the level of the ocean can exist. All of the deposits along the immediate shore between the Yahtse and Yakutat bay have the characteristic topographic features resulting from the action of waves and currents and do not even suggest the proximity of a great glacier.

Recent advance.—On the eastern margin of Malaspina glacier, about four miles north of Point Manby, there is a locality where the ice has recently advanced into the dense forest and cut scores of great spruce trees short off and piled them in confused heaps. After this advance the ice retreated, leaving the surface strewn with irregular heaps of bowlders and stones and inclosing many basins which, at the time of our visit, were full to the brim. The glacier during its advance plowed up a ridge of blue clay in front of it, thus revealing in a very satisfactory manner the character of the strata on which it rests. The clay is thickly charged with sea-shells of living species, proving that the glacier, during its former great advance, probably extended to the ocean, and that a rise of the land has subsequently occurred. This is in harmony with many other observations which show that the coast adjacent to Malaspina glacier is now rising. The blue color of the subglacial strata is in marked contrast with the browns and yellows of the moraines left on its surface by the retreating ice, which, in common with the fringing moraines still resting on the glacier, show considerable weather-

ing. Among the shells collected in the subglacial clay Dr. W. H. Dall has identified the following;

Cardium gronlandicum, Gronl.
Cardium islandicum, L.
Kennerlia grandis, Dall.
Leda fossa, Baird.
Macoma sabulosa, Spengler.

Similar shells, all of living species, were previously found at an elevation of five thousand feet on the crest of a fault scarp at Pinnacle pass, showing that recent elevations of land much greater than the one recorded in the marine clay just noticed have taken place. In fact there are several indications that the coast in the vicinity has been rising and that the same process is still continuing.

ISRAEL C. RUSSELL.

THE OSAR GRAVELS OF THE COAST OF MAINE.[1]

In the interior of Maine we find the long osars interrupted near the tops of transverse hills crossed by the glacial rivers, and still more interrupted on steep southern slopes. In such situations it is evident that the velocities of the osar rivers would be greater than the average, with the result that the rivers swept their channels clear of sediments. The conditions were those of transportation by the glacial rivers rather than deposition.

If we follow the osars southward toward the ocean we find at about the average distance of thirty miles from the shore that the osars begin to be interrupted in a different manner from that in the interior. Gaps begin to appear in the ridges in level ground where the land slopes could not cause an accelerated motion of the glacial rivers. Indeed, the gravels more often appear on the tops of low hills than in the lower grounds. Going southward the sizes of the ridges become on the average smaller, their materials rather coarser, the intervals longer, and finally near the northern ends of the bays or fjords of the coast they disappear. If they continue farther southward or into the sea, it is in masses that are so small as to be covered out of sight by the marine beds. The coastal towns are usually covered by clays, and road gravel is often in great demand. The vigilance of town officers has often detected beneath the marine clays small mounds of gravel that form the southern ends of gravel systems. To the south we reach a region where no gravels have been found. When we find an osar system graduating into mounds so small that not even the selectmen of a Maine town can find water-washed road gravel, we may be sure that our osar has come practically to an end. I have examined the charts of the Coast

[1] Condensation of chapters of a report on the Glacial Gravels of Maine, written for the U. S. Geological Survey.

Survey showing the sea bottom for a few miles off the coast. If there were any broad gravel hills 100 to 150 feet high, such as are found thirty miles north from the bays, they ought to be shown, and I do not find them. The charts often report gravelly bottom but it is uncertain whether this is till or glacial gravel. I find no evidence that these soundings showing gravel are connected with ridges of any considerable size. While then it is as yet impossible to know the geological significance of the gravel reported on the sea floor, yet in most cases the gravels end so evidently north of the shore that the interpretation is distinctly favored that none of the gravel systems reach far beneath the sea. No osar gravels have I been able to find on the islands situated south of the apparent ends of the gravel systems.

There are other significant peculiarities of the coastal gravels than those to be named in this paper, and many collateral or alternative questions and hypotheses had to be worked out. For the present we confine our attention to the three following characteristics :

1. The decrease in the average size of the glacial gravel masses as we go toward the coast till they often become cones not more than twenty or thirty feet in diameter and four or five feet high. In general, the marine clays are twenty feet or more in depth and would easily cover out of sight masses smaller than those above named.

2. The increasing discontinuity of the osar systems, the gaps between the successive ridges, massive mounds or plains, lenticular hills, domes, cones, and mounds increasing from a few rods up to two or three miles.

3. The practical ending of the osar gravels near the north ends of the fjords (fjord line). It is not meant to assert that there are absolutely no osar mounds beneath the sea or on the land south of the discovered gravels. But if any exist they are hidden by the marine beds, and are so insignificant in size as compared to the osar gravels found a few miles farther north that for all practical purposes we may assume that they end. If the osar mounds go on decreasing as fast southward as they do

within the last few miles of their traceable courses, they certainly must entirely disappear within three to five miles of their apparent endings. We omit here the overwash gravels that were deposited in front of the ice beneath the present ocean.

It is to be noted that these gravels are in lines or systems, and often toward the north pass into continuous osars. They are regarded as having been deposited by a single glacial river, that is, all that are classed as a single system. The intervals between the separated gravel masses are not due to erosion of a once continuous body. But the problem relates to the reasons why a single glacial river deposited sediments at intervals here and there within its channel.

In placing the problem before us, we have to consider the extent of the region in question. The above-named characteristics are associated with each other along two hundred miles of coast. Every few miles throughout this district we come to places where a glacial river has left its sediments. All these gravel systems exhibit the first two of the above named characteristics, and all but four or five, the last. Three osars end at the shore but near the north end of Penobscot bay several miles north of the general fjord line. Two others, perhaps the largest systems in the state, come down to the shore and the soundings seem to support the conclusion that they extend for a short distance under the sea. Horizontally, these changes mostly take place within a belt not far from thirty miles in breadth; vertically in most cases between sea level and the two hundred feet contour. The last named, the ending of the gravels, occurs between contours hardly fifty feet apart.

It is granted that the sea in late glacial time stood along the outer coast line, a little more than two hundred feet above its present level. In the interior its elevation was more than twice this height. All the beaches along the outer coast, whose height I have measured, have nearly the same elevation. In other words, the surface of the sea in late glacial time was substantially parallel to its present surface in the direction of the coast, though at a higher level.

In the coastal region we find numerous marine glacial deltas deposited in front of the ice by glacial rivers that flowed into the sea, but we do not find such frontal or overwash sediments as naturally form in front of glaciers terminating above sea level. These and other facts prove that the ice had not all melted over the coastal region before the advance of the sea. The subsidence of the land (apparent advance of the sea) either preceded the retreat of the ice over the coastal region or accompanied it in such a manner that all the land free from ice was covered by the sea as fast as the ice melted, up to the time when the sea had advanced northward to the highest beach. That is, up to this time, all the subglacial streams poured into the sea at the ice front and not on land above the sea. It follows that the causes of the ending of the osar systems north of the shore not only acted parallel to the present and former surface of the sea, but also in a region where the basal ice was bathed in sea water.

The presence of deep glacial pot-holes in considerable numbers near the coast proves the existence of subglacial streams in that region. Since there are no glacial gravels near these pot-holes, we have proof that there were rapid subglacial streams that left no gravels. Evidently their velocities were such that they transported all their sediments beyond our field (out into the region now under the sea). For years my conclusion has been that the osar rivers of the coastal region of Maine were all subglacial. Assuming the subglacial streams, the problem now resolves itself into this: How happened it that as the subglacial rivers approached the coast, they all found themselves able to sweep their channels free from sediments at nearly the same elevation?

Without here pausing to consider the genesis of the subglacial tunnels, we confine ourselves to the question, how are the tunnels enlarged? Two physical agencies do most of the work. First, mechanical erosion; second, melting of the ice walls by surface waters. In the case of ordinary mountain glaciers there is usually considerable land on the mountains that is bare of ice, and thus water warmed on the land passes beneath the ice and

helps to enlarge the subglacial or englacial channels. But, in the case of ice sheets covering all the land, the only heat available for enlarging the tunnels (omitting the small amount of basal heat) is the heat absorbed by surface waters and carried by them beneath the ice. It is known that the waters of surface melting often collect in superficial brooks and torrents of considerable size. The absorption of radiant energy from the sunlight is instantaneous, or at least much more rapid than the conduction of this energy as molecular heat from the water to the ice with which it is in contact. Under sunlight all surface waters become warmed a little above 32°, and, as they plunge beneath the ice, they give up their surplus heat to help melt the walls of the subglacial channels. This, I infer, is the most efficient of all the agencies that help to enlarge the subglacial tunnels. Enlargement of the subglacial tunnels is not uniform. Thus, where a surface stream pours beneath the ice and brings a fresh supply of heat into the tunnel, there would be more rapid enlargement than elsewhere. For various reasons, not necessary to be discussed here, the enlargement of the tunnels proceeds unequally.

Given a tunnel gradually enlarging till sedimentation begins, this sedimentation will commence at the most favorable places, as at the local enlargements, or at an obstruction. If, now, the size of the tunnel, or rather the ratio between the tunnel capacity and amount of water increase, sedimentation will take place at more frequent intervals, and if the tunnel becomes large and rather uniform in size, the sediments will form a continuous ridge.

Various causes can be adduced why a glacial stream should deposit a diminishing quantity of sediment, but the controlling cause and almost the only one admissible under the peculiar local circumstances is the following: We grant that as we go southward toward the distal extremity of the glacier the supply of drainage water will increase, as in all drainage systems. But all these surface waters take with them heat as they pass beneath the ice to help enlarge the tunnels. Thus, as it were, each

region of the glacier furnishes the heat to enlarge the tunnels within its own limits. This is the natural career of ordinary ice sheets above the sea.

An important law of the enlargement of subglacial tunnels depends on the velocity of ice movement. Subterranean waters, as those of the limestone caves, go on enlarging their channels from age to age, because they act continuously on the same body of rock. But the subglacial tunnel cannot become thus enlarged, because of the constant renewal of the ice. Other things being equal, the enlargement of the subglacial tunnels is directly proportional to the time during which it is being enlarged, and inversely as the rate of ice flow. Obviously, when the flow is rapid the tunnel never becomes very much enlarged, for before this can happen the ice at any given part of the channel is pushed on to the distal extremity and disappears by melting or by berg discharge.

The details, here omitted, prove there was probably a small acceleration of the rate of ice flow as the coast of Maine was approached, hence the rate of enlargement of the ice channels would not increase so rapidly as the supply of water of local melting. But the surface of that region is much diversified with hills and valleys. The rate of ice flow would be most rapid in the deeper north and south valleys, and would be retarded in the lee of the higher transverse hills, of which there are several long systems. If differences in the rate of ice flow were the only cause of different rates of ice channel enlargement, then we ought, on such an uneven coast, to find evidence of the fact in the distribution of the gravels. Examination shows that this was a real cause of varying rates of enlargement, but it was a minor cause. This cause alone could not have enabled all the subglacial rivers to clear their tunnels of sediments at the same or nearly the same horizontal line. It would have acted at various levels, according to the conditions for rapid ice supply from the north.

We have seen that the ice in late glacial time flowed into the sea in the coastal region of Maine. It remains for us to inquire

what is the effect of the flowing of a glacier down into a body of water upon the enlargement of the subglacial tunnels. In such a case the tunnels and all crevasses opening into them are permanently filled with water up to the level of the surface of this body of water. But it is by the crevasses that the waters of local melting get down into the subglacial tunnel. The permanent water in the crevasses is at the temperature of 32°. As the waters of surface melting in the region whose basal ice is submerged in the sea or other body of water pour into the crevasses they cannot at once fall to the ground and enter the tunnels, but they fall into the water in the crevasses that already fills them to the level of the permanent body of water. The large streams find their way pretty directly into the tunnels, but all the smaller streams and trickles become so mixed with the cold waters in the crevasses that their heat, instead of being consumed in enlarging the tunnels, is largely expended in melting the ice walls of the crevasses above the level of the tops of the roofs of the tunnels.

Thus the flowing of a glacier down into the sea interferes with the natural transfer of heat beneath the ice whereby the tunnels are enlarged in large part. But the supply of surface waters is the same over the area whose base is submerged as elsewhere. The conclusion follows, that as we go toward the distal extremity of a glacier that flows into a body of water, the supply of drainage waters would be increased more rapidly than the tunnel capacity. This would result in increased velocity of the rivers, with a corresponding increase in power of transportation. In other words, they would do just as the osar rivers of Maine did as they approached the coast—would deposit sediments at longer and longer intervals, and in smaller quantities, and finally would sweep their tunnels free from all sediments.

Now it is certain and inevitable that the submergence of the basal ice should restrict the enlargement of the subglacial tunnels, yet it is an open question whether this was sufficient to account for the peculiar development of the coastal gravels.

We have seen that these changes take place within a belt not

far from thirty miles wide. Without assuming any definite rate or rates of ice movement we can at least all agree that it would take many years for the ice to advance such a distance. An obstruction to the natural transfer of heat beneath the ice, and consequent enlargement of the tunnels, though it might be slow in its action, would, after a term of years, have a cumulative effect on the development of the tunnels, at least in cases where the subglacial rivers flowed in channels parallel with the ice flow.

We have seen that the three features of the coastal gravels above stated are associated together over a wide area, and would appear to have a common origin. Glacial rivers of different lengths, from five up to more than one hundred miles, all show the same development. At almost the same elevation they all were able to sweep their tunnels clear of sediments. We must seek for some cause capable of acting along two hundred miles of coast in lines approximately parallel to the surface of the sea. What but the sea itself could do this under so many varying topographical and glacial conditions?

Rightly interpreted, it would appear that the termination of the gravel systems north of the shore line is itself a proof of the former elevation of the sea. We may leave it as an open question how far the sea acted in other ways—such as by diminishing the effective "head" of the subglacial streams, etc., but that the sea was chiefly responsible for the peculiar development of the coastal gravels, I am persuaded, is the best interpretation of the facts. And of all the ways in which the sea or other body of water that submerges the base of a glacier affects the subglacial streams and their tunnels, I have been able to discover none so potent as that which is above described, whereby the enlargement of the tunnels is obstructed.

Where subglacial rivers flowed up and over transverse hills, as they often did in Maine, there would be a body of slack water in the tunnels, like a sewer trap, on the north sides of the hills. Some of these bodies of slack water or dams on the north sides of hills were from five to ten or fifteen miles long, and in one

extreme case about twenty miles. The ice would be so long passing over such distances that we could expect that the basal water would restrict the enlargement of the tunnels sufficiently to show a characteristic development of the gravels, such as narrowness of the osars or gaps without gravels. While in such situations I nowhere find so extreme a development as in the coastal region, yet there are numerous facts that are best interpreted by the hypothesis that the basal waters of the slack water dams in the subglacial tunnels did somewhat obstruct the enlargement of the tunnels; and thus far I have found none inconsistent with that hypothesis.

The critical reader will have noted that the belt of transition of the coastal gravels of Maine is approximately parallel to the ice front at one stage of the retreat of the ice. It is also somewhat parallel to the southern margin of the *névé*. It has been necessary to consider whether the coastal gravels were retreatal phenomena, connected with some late stage of the ice sheet's history, also what effect would be produced by the retreat northward of the *névé* line, whether the discontinuous gravels were due to the gradual rise of the sea, etc. The result has been to relegate all the suggested agencies to a subordinate position with respect to the two causes above named—a probable small acceleration of ice flow near the coast and the limited enlargement of the subglacial tunnels over the area whose basal ice was submerged in the sea.

George H. Stone.

THE HORIZON OF DRUMLIN, OSAR AND KAME FORMATION.

In an article in the first number of this journal on the nature of the englacial drift of the Mississippi basin, I endeavored to show by evidence drawn from a wide area of the interior that erratics dislodged from the summits of the hills of crystalline rock in the northern region by the Pleistocene ice-sheet were borne south within the ice in such a way as to be kept separate from the basal material throughout the whole course of their transportation, and that they were at length let down upon the surface of the basal drift at the margin of the ice as a separate deposit. The evidence seemed to force the view that the basal material was not carried upward by transverse ice currents even into the heart of the glacier much less to its surface. The facts there cited seemed to make it clear that there is not only a theoretical but a practical horizon of demarcation between the englacial drift and the basal drift, and that under circumstances of this kind—and they seem to have wide prevalence—there is little or no confusion of the two. Very possibly this conclusion does not hold equally good in very hilly or mountainous regions.

In carrying out into further application this distinction, it seems well to specify the precise sense in which the term englacial is used. It may be applied to any erratic material that, at any time during its transportation, may be enclosed within the ice even though it be essentially at the bottom of the glacier and may have been actually at the bottom a little before and may again be at the base a little later on; or it may be applied, less technically but more significantly, to that only which is embedded in the heart of the ice and borne passively along with it free from basal influences until it is at length brought out to the surface of the terminal slope by the agency of ablation.

It is clear that all erratic material as it was brought to the front edge of the ice appeared either on the surface or at the base. There is here a sharp physical horizon of demarcation. If the material that had been basal some distance back from the edge was carried up to the surface, or carried up so far into the body of the ice that the surface was brought down to it by ablation near the border, it is evident that it must have become commingled with that which had been englacial or superglacial from the moment it was dislodged from its parent hills, and hence this horizon of demarcation would not distinguish between the two classes of material as such. The distinction would rest upon mode of transportation and deposition. But if the interpretation of the article referred to is correct and holds good generally in similar regions, the horizon becomes a plane of separation between the classes of material as well, and assumes much importance in practical glaciology. It was, however, obviously not an absolute plane of demarcation, even at the border of the ice, and when we attempt to apply it to sections lying farther back, it needs some qualification.

Without doubt material which was picked up by the ice along its base was thrust up into it to greater or less heights. As a particular instance, beds of rock which were inclined upward toward the oncoming ice were obviously disposed to thrust themselves into it as they were being tilted out of their positions. They appear to have rotated upon their lower edges, as upon a hinge, and were probably only removed from their places after they had been turned into a vertical position or perhaps somewhat beyond it. They were then almost wholly embedded in the ice, and so, in a limited sense, they were englacial. So also it is extremely probable that, in the case of undercut ledges, sharp ravines, narrow gorges, and similar very abrupt inequalities in which the surface was suddenly depressed, there was more or less overriding of the basal currents of the ice and consequent incorporation or overplacement of the material held in the bottom of the overrunning portion. But notwithstanding the fact that this material became englacial in a limited sense, because

it was not absolutely at the bottom of the ice, I think, in a genetic view, it is to be regarded as basal unless it was lifted so high into the body of the glacier as to be borne onward thenceforth entirely within the body of the ice and free from basal influences so that it was at length carried out to the surface as it approached the terminal edge, and was deposited as superglacial material. If the material remained approximately at the bottom of the glacier and again descended to the absolute base of the ice, it seems to me best to regard it as basal, even though it may be, for a time, completely enveloped within the ice. This seems best, because it represents the significant factor in the operation. In origin, it was basal, and, in the end, it became basal. It was only englacial by accident, temporarily.

Opposed to the agencies that tended to carry material from the absolute bottom of the ice into its basal portion to limited heights, there were several agencies that tended to bring it back to the absolute bottom. (1) The conduction of internal heat contributed slightly to this by melting away the base of the ice. The annual amount was undoubtedly very small, but the cumulative effects upon the bottom of any particular column of ice during the last five hundred miles of its journey (and this much is involved in certain aspects of the problem) was probably very appreciable and was manifestly greater in proportion to the slowness of the ice movement. (2) Basal friction undoubtedly gave rise to a much larger wastage and so lowered the embedded debris. (3) The introduction of warm waters from the surface, through the agency of crevasses, also caused wastage of the bottom, but this was obviously limited to such portions as were accessible to these waters and the effects were unequally distributed, although the positions of the streams undoubtedly changed from time to time, and this tended to spread the effects more generally over the bottom. (4) It is probable that there was a certain amount of penetration of solar rays through the ice. As the surface of a glacier is usually granular, only a minor portion of the sun's rays probably succeeded in penetrating to the transparent ice below. But such portions as reached this

were competent to traverse very considerable depths of ice without being entirely absorbed, being chiefly waves of short vibration. Those who have been beneath glaciers have observed that the amount of transmitted light is not inconsiderable. The transmitted rays of short vibration, so far as they reached the bottom, were arrested and, by transformation to rays of longer vibration, brought to bear upon the base of the glacier. The basal wastage from this source may be presumed to have increased somewhat in proportion as the ice thinned towards its margin, but this would be offset to some degree by a probable increase of surface detritus that would cut off the rays. The combined effect of these agencies would appear to have been not inconsiderable.

(5) In any vertical section of a glacier the lagging of the basal portion causes the plane of the section to lean forward, which means that each part is brought nearer to the bottom, carrying with it whatever material is enclosed. This being a general phenomenon justifies the conclusion that the tendency of the ice of the interior of a glacier is to flow obliquely forward and downward. Exceptions to this may be found when the resistance of a given portion of the base is greater than that of the portion immediately in its rear, in which case the latter may tend to flow over the former, but this will be reversed when the ratio of resistance is changed and would be, at most, but a variation of action, not a general law of action.

The combined effect of all these agencies was, if I reason correctly, to bring back to the base of the ice any material that owing to the special causes named, or to others, had been forced up into the lower parts of the ice. They tended to preserve the basal character of whatever had once become basal. And this seems to be supported by observations on existing glaciers.

These considerations have a very specific bearing upon the horizon at which drumlins, osars (eskers), and kames were formed. These all contain large quantities of local material, of basal derivation. If the view here stated is correct, these must be very strictly basal deposits, in general. There are doubtless

some qualifications and exceptions. This conclusion is not at all new, for, as is well known, it has been reached by several students of these phenomena quite independently. But an approach to the question along the line of evidence presented by *bowlder belts* and *bowlder trains* has its own advantages. It bears particularly upon a new view of the origin of drumlins recently advanced by one of our most experienced glacialists in which they are held to have been chiefly formed from englacial drift which "had become superglacial by ablation and was afterwards enclosed as a stratum within the ice-sheet, being thence amassed in these hills."[1]

In the midst of the drumlin area of south-central Wisconsin, there arise from beneath the Paleozoic strata a few scattered knobs of quartzite and quartz-porphyry from which erratics have been derived and borne away to varying distances, constituting bowlder trains of the most definite type. These are radically different from the bowlder *belts* discussed in my previous paper. The quartzite outcrops near Waterloo, in Jefferson County, are the most favorably situated for the purposes of the present study, because they are right in the heart of the most pronounced drumlin area and have made large contributions to the erratic content of the drumlins themselves. My associate, Mr. I. M. Buell, has been engaged for some time in a very careful study of the abrasion which these quartzite outcrops suffered from glaciation and of the distribution and special relationships of the erratic material derived from them. The drift movement was here to the south-southwestward and quartzite blocks derived from these outcrops enter in great abundance into the constitution of the drumlins lying in that direction. Several features of their distribution and nature are worthy of special note.

1. The quartzite bowlders are not simply scattered over the surface of the drumlins, but are distributed throughout their entire mass so far as accessible to observation. As the drumlins bear evidence of gradual accretion, it seems necessary to suppose that they were built up by successive additions of material

[1] "Conditions of Accumulation of Drumlins," Warren Upham, *American Geologist*, December, 1892. pp. 339–362.

derived from a stream of drift passing over the quartzite ledges and making constant additions from them.

2. The drumlins are found to be filled with quartzite erratics immediately in the lee of the ledges. There are even drumlins which lie directly upon the ledges and envelop them in large part, which are found free from local quartzite derivatives on their stoss ends, but are inset with them in their lee ends. The quartzite content of the leeward portion ranges, in observed sections, from 5 per cent. to 10 per cent. of the whole drift. In one case, Mr. Buell found an isolated drumlin to contain all of the quartzite of its particular kind observed in the vicinity. It evidently completely envelops the parent ledge and retains the most of its derivatives. Several bowldery mounds, that may be regarded as drumlins in miniature, occur in the immediate lee of the ledges, in which the quartzite drift was estimated to comprise from 20 per cent. to 75 per cent. of the whole. The material, in these instances, appeared to be chiefly former talus of the quartzite outcrops. Setting in thus promptly immediately at the quartzite outcrops, the erratics are found to diminish very markedly in proportion as the distance increases. A mile and a half away from the outcrops, a careful estimate of the quartzite content gave 3 per cent. of the whole mass of the drift. The average for the area between 1 and 6 miles is 1-1½ per cent.; between that and 20 miles 1 per cent.; between that and 45 miles .364 per cent., and in the terminal moraine .0477 per cent. The surface distribution shows a similar diminution. The estimated amount of quartzite on the very bowldery mounds near the ledges was 17,700 cords; at other points within six miles of the outcrops 12,650 cords; at medial points 1,409 cords; on the terminal moraine, about 45 miles distant, 747 cords. This very rapid diminution in the quantity of quartzite erratics is significant in showing that the element of resistance to transportation was an influential factor. This is precisely what is to be anticipated on the hypothesis that these bowlders were pushed or dragged along the base of the ice. It seems very far from what is to be expected, however, on the

hypothesis that the erratics rose in the ice and were transported englacially in any considerable degree. In this case, the greatest accumulation should have been at the terminal moraine where the ice halted longest. It seems to be also difficult to understand, on the hypothesis offered by Mr. Upham, how the drumlins lying immediately on the ledges and immediately in their lee could have been filled so largely with quartzite-bowlders. Certainly the bowlders could not have risen in the ice so high as to have become exposed at its surface by ablation and then have been overflowed by a new accession of ice and moulded into the drumlin form, and at length have been let down by the melting of the ice beneath without more forward movement than observation shows. The simplicity of the facts do not seem to tally with the complexity of this theory.

3. The amount of abrasion which the bowlders suffered bears specifically upon the question of the mode of their transportation. The parent outcrops gave rise to erratics of three kinds. (1) In Paleozoic times the ledges stood as islands in the seas, and there accumulated about them very coarse conglomerates of quartzite. From these, a portion of the erratics were derived in an already rounded condition. The character of this rounding and the superficial changes the pebbles underwent before the glacial period made it possible for Mr. Buell to distinguish these with measureable certainty in following the train until abrasion had destroyed their surface characters. (2) Talus blocks accumulated about the bases of outcrops before the ice invasion that formed the drumlins. There was an earlier invasion which bore quartzite erratics westward. The later invasion bore them southwestward. The talus blocks under consideration are, perhaps, in the main, those that were derived from the quartzite knobs in the interval between the two. They are distinguishable from blocks disrupted by the ice by means of the weathered character of their several surfaces, so long as these remain unabraded. (3) The third class of erratics are those that were derived by direct action of the ice upon the parent knobs. These are distinguished by their unweathered fracture surfaces.

Among five hundred bowlders examined by Mr. Buell at two railroad sections, distant less than three miles from the most remote of the parent ledges, only ten were noted that did not plainly show by rounded edges and blunted angles the effects of glacial attrition. At a point less than twelve miles distant, the abrasion had so far obliterated the surface characters that it was hardly possible to determine to which of the three classes above indicated the erratics had originally belonged. Farther on, the evidences of abrasion are still more marked. The degree of abrasion did not appear to be equally great in the case of some of the bowlders found on the crest of some of the high ridges and on the surface of the terminal moraine. Mr. Buell's observations were made with the hypothesis of englacial transportation in mind as an accepted working hypothesis, but with only meagre results in the drumlin area. Studies at two points on the slope of the outer ridge of the terminal moraine and on the edge of the overwash plain gave fifty-six bowlders that were only slightly affected by glacial abrasion and eighty-eight which showed by their rounded forms and scratched surfaces the effects of severe glacial reduction. While therefore the observations do not exclude the hypothesis of a small amount of englacial transportation, if slight abrasion be taken as sufficient evidence of this, they limit it to a quite trivial factor of the whole mass.

The combined testimony of the foregoing facts seems to me quite decisive in its bearing on the proposition that the derivation, transportation and deposit of the quartzite bowlders was almost exclusively subglacial or at least closely basal. As these bowlders enter into the structure of the drumlins from base to summit, and are mingled with much other local material, the foreign element being relatively small, they seem to compel the same conclusion respecting the whole of the material which was built into the drumlin forms.

Mr. Buell has found what he regards as satisfactory evidence that an older train of bowlders was carried directly westward at the time of the earlier drift and that the later ice movement toward the southwest crossed this train obliquely and distributed

it over a much greater area than it originally occupied, forming a secondary train. The erratics of this secondary train, he finds much smaller in general and marked by greater evidence of glacial reduction than those of the unmodified later train. This has a double bearing upon the question of the origin of the drumlins in that it indicates basal transportation in both epochs and in that it indicates a direct accumulation of the drumlins *de novo* during the later incursion. It seems to exclude the view that the drumlins are remnants of the older drift; for, since the older train was westerly, there would be no quartzite material in the old drift lying southwesterly from the outcrops, and hence none would appear within the body of the drift in that region when worn into drumlin forms. But it is just here that quartzite erratics appear in their greatest abundance and permeate the body of the drumlins most impartially. The direct south-southwesterly bowlder train is so predominant that the older, and now more scattered, westerly one was not recognized by the earlier observers.

The testimony of these *bowlder trains* (basal phenomena distributed along the line of drift movement) combined with that of the *border belts* (superficial phenomena distributed transversely to the drift movement and parallel to the edge of the ice) seems therefore to add some special weight to the already familiar evidence supporting the view that drumlins are strictly basal aggregations.

There are no well defined osars (eskers) in this drumlin region, but there are tracts of gravelly knolls and ridges some of which seem to represent longitudinal glacial drainage lines, and so, genetically speaking, to stand for the esker phenomena. Aggregates of the kame type, or of an unclassifiable type of this general order, occur not infrequently among the drumlins. In connection with the moraines bordering the district, kames of the typical variety have an abundant development. Into all these, so far as they lie within the area of quartzite distribution, the quartzitic material enters in even greater abundance than into the average unmodified till of the drumlins themselves or

of the moraine. The mean of several observations upon kame-like accumulations of gravel lying within ten miles of the parent outcrops gave Mr. Buell 5 per cent. of quartzite, in the interior material accessible in sectional exposures. At points about midway between the parent ledges and the terminal moraine, forty-five miles distant, the average amount was found to be 1.2 per cent. Measurements made nearer the limit of the later drift showed .39 per cent., while on the margin, the quantities were usually found too small to be estimated in percentages.

It thus appears that the law of distribution found in the drumlins holds good for the kames save that the relative percentage of quartzite in the latter is greater than in the former; a fact which finds its explanation, in part certainly, in the fact that the clayey and other fine material of the drumlins enters into the estimate of percentage for them while it does not in the case of the kames, it having been chiefly washed away; and perhaps also, in part, in the fact of greater resistance to wear on the part of the quartzite.

These kame-like accumulations sometimes lie in the lee of the drumlins and form a part of the common hill or ridge, their contours blending into the common contours of the drumloid form, so that there can be no doubt that the two portions were simultaneous in formation, and that the horizon and environment of their accumulation were identical. In other instances, they are associated with cols or with valleys among the drumlins in such a way as to leave no doubt that the kames and drumlins were closely associated and essentially contemporaneous in formation. As some of these kame-like forms lie very near the parent quartzite ledges, it seems quite impossible to suppose that the quartzite erratics were borne to the surface by internal cross movement of the ice, and afterwards let down so near to the origin of the material as we find them. There seems, therefore, no escape from the conclusion that these are also very strictly basal phenomena, being but assorted and re-aggregated portions of the common drift of the drumlins and the general ground moraine.

Returning to the region of the superficial bowlder *belts* in Illinois, Indiana, and Ohio, we find hillocks of the kame type distributed throughout the same tracts as the bowlders, indeed, practically lying beneath the bowlder belts themselves. Some of these I described nine years ago in the American Journal of Science in an article entitled "Hillocks of Angular Gravel and Disturbed Stratification."[1] Additional evidence of the same import has been since gathered. Among the materials of these kame-like aggregates, it is not uncommon to find a complete series of gradational forms, ranging from incorporated masses or tongues of typical till of the ground-moraine type, through partially modified masses and layers of half-till, half-gravel, to completely assorted and stratified material, thus showing every stage of the derivation from the common underlying and surrounding till. The attrition of the material shows a like gradation. In some portions the clayey constituents of the till have been simply washed out leaving the rock fragments which show almost no perceptible wear from water. In others, the rounding has been more considerable, and in still others, there has been a reduction to the common rounded gravelly type. Even this is not usually well rounded. The less modified fragments not uncommonly show glacial striation. All these variations occur within the limits of a single hillock, and are often so intimately associated as to compel the conviction that the gravel is but a partially assorted derivative from the till of the region. In some of these hills the stratification is disturbed, not as though the beds had been let down by the removal of ice below, but as though they had been pushed horizontally by glacial pressure. The essentially local derivation of the material is demonstrated by the very notable presence of rock fragments derived from the formations of the neighborhood. More than half the material is not infrequently made up of limestone whose origin must be much nearer at hand than that of the superficial bowlder belt. An analysis representative of the gravel and sand of one of these kames gave as much as 70 per cent. magnesian limestone.

[1] Am. Jour. Sci., vol. XXVII, May 1884. Pages 378–390.

It is probably safe to say that in selected instances at least 90 per cent. of the material was derived from the Paleozoic series and more than half of this from the vicinity. This is, however, too large an estimate for the average, but the local constituents were never seen to be other than pronounced if not predominant. Material of local derivation also enters into the constitution of the sand and clay as well as the coarser material showing that the hillocks are made up not only of the glacially ground rock-fragments, but of the glacial grindings. The whole aspect of the material of these kames is so strikingly in contrast with that of the superficial bowlder belt and points so definitely to their derivation from the common sheet of subglacial till as to seem to put beyond doubt the view that they are quite strictly basal in formation.

Osars of the typical variety have comparatively few representatives in the plain tracts of the interior, but several well characterized instances occur. It is notable that, in most of these instances, as pointed out by Mr. Leverett, who has perhaps carefully studied a larger number of them than anyone else, they often lie in river-like channels cut into the till sheet of the region. There are perhaps a dozen of these that have been studied, varying in length from a few miles to about fifty miles. These channels have the characteristics of river troughs, and usually stand so related to the margin of the ice as to seem to indicate that they were lines of subglacial drainage during the same glacial stage as that in which the osars were formed. These channels are so related to the surface slopes that they could not have been formed by free open-air streams. The restraining aid of ice seems necessary. While no demonstration of the history of their formation can be claimed, the most plausible explanation appears to be that the river-like channels were cut by subglacial streams at a time when the urgency of the ice was such as to compel basal cutting, and that, subsequently, when the pressure of the ice was less insistent, and its motion feebler, the draining stream was permitted to fix its channel in a tunnel cut in the under surface of the ice, which

otherwise occupied the channel previously cut, and that the stream gradually built up its gravels within the tunnel so formed, essentially as indicated by Professor Russell in the case of tunnels under the Malaspina glacier. While the inferences drawn from this peculiar association of the osar ridges with river-like channels cannot be urged with the same force as the preceding considerations, they seem to support them in some degree. The constitution of these osar ridges is of the same local character as that of the kames above discussed except that perhaps it is less narrowly local and less intimately related to the underlying formations. The difference, however, is not marked.

From the foregoing evidences, the inference is drawn that the osars and kames of the plain region of the interior are basal phenomena in a degree almost as complete as the drumlins or the ground moraine. Inferences from such evidences as have been cited cannot, however, be applied with so much rigor in the case of osars and kames as in the case of drumlins, for the subglacial streams, that are held to have formed them, cannot be assumed to have always pursued strictly basal courses. Conditions may be supposed to have arisen which would have forced the streams into channels above the base of the ice, or even up over the ice in the thin marginal portion, so that accumulations may have taken place that were less strictly basal than those of the drumlins, and it is of course possible that kames and osars may have been formed, in particular instances, out of the englacial and superglacial material of the ice; but, following what seems to me the legitimate teachings of the foregoing lines of evidence and of observation, there seems warrant for concluding that such instances, though theoretically possible, are practically rare. I beg that it may be observed that these conclusions are drawn from the phenomena of the plain region of the interior and are applied to it, with the full recognition of the possibility that in hilly and mountainous regions modifications of the conclusions may be necessary.

T. C. CHAMBERLIN.

A CONTACT BETWEEN THE LOWER HURONIAN AND THE UNDERLYING GRANITE IN THE REPUBLIC TROUGH, NEAR REPUBLIC, MICHIGAN.

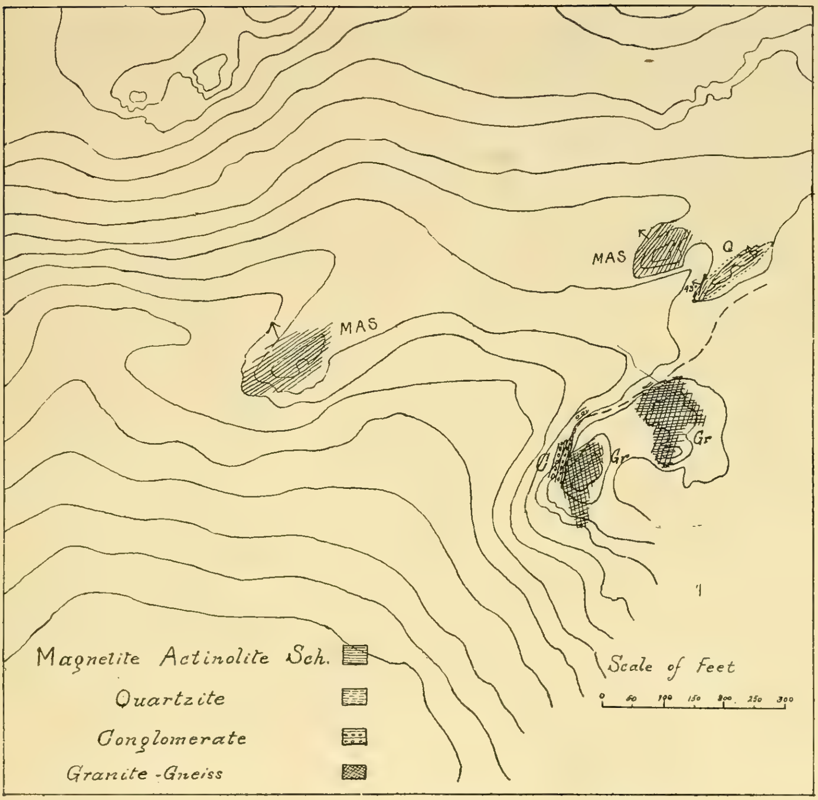
I.

THE lowest member of the Lower Huronian rarely outcrops in the Republic trough. Brooks on his large scale map of Republic Mountain and vicinity, 1869, shows but two exposures of the lower quartzite. They lie south of the mine, in the bend of the horseshoe, and were discovered by Pumpelly and Credner in 1867. Some 250 or 300 feet southwest of the westernmost of these, I have recently found a conglomerate resting upon granite, the contact of the two rocks being very well exposed. It is interesting to note that the locality is very close to that figured by Brooks[1] to show that the strike of the quartzite and of the magnetite-actinolite-schist just above it, runs directly across the foliation in the underlying gneissoid granite. From this he inferred an unconformability between the Huronian and the Laurentian.

II. GENERAL RELATIONS.

The accompanying map will make plain the immediate relations between granite, quartzite, and magnetite-actinolite-schist. The magnetite-actinolite-schists occupy a broad belt in the northern part of the area represented on the large scale map (Fig. V), striking between N, and E. at various angles, and dipping W. of N. from 35°–40°. The alternating layers of silica, actinolite, and magnetic, or two or all combined, which compose this rock, show both a considerable degree of plication, and also a coarse, cross cleavage which strikes between N.45°W. and N. 60° W., or roughly in the direction of the axis of the trough.

[1] Geology of Michigan, Vol. I, part I, p. 126.



N. W. ¼, N. E. ¼, Sec. 18, T. 46 N. R. 29 W., Mich.

The map is from a tracing of a manuscript copy of Brooks' Map, 1 inch = 200 feet, in the possession of the Republic Iron Co. The area represented on the large scale covers a little more than the N. W. ¼ of the N. E. ¼ of Sec. 18, T. 46 N., R. 29 W. The sketch to small scale shows the relation to the trough as a whole. (Fig. V.)

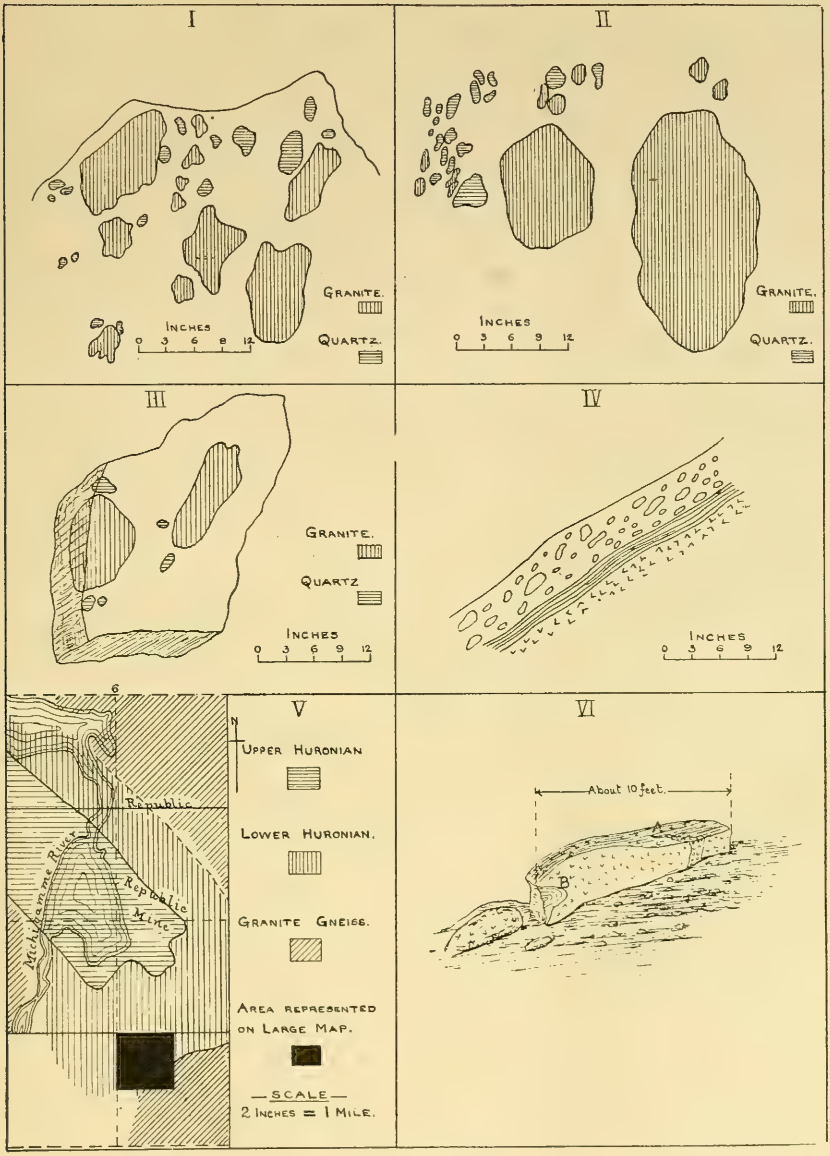
Below the magnetite-actinolite-schists and separated from the nearest exposure by a covered interval of 50 feet is the outcrop of quartzite discovered by Pumpelly and Credner. The outcrop runs about 175 feet along the strike and 30 feet across it. At the N. E. end the strike is about N. 55 °E., and at the S. W. end about N. 20° E., the dip in both cases being to the W. of N.,40°–45°. For the most part the rock is massive and heavily bedded, but the higher portion shows unmistakable sedimentary banding, and even false bedding.

In external appearance and in composition the rock is a very coarse-textured, light-colored quartzite, made up almost entirely of quartz, with some muscovite and chlorite as subordinate constituents. Under the microscope, probably because obliterated by shearing, no original rolled grains were seen, although several slides were examined. Red garnets are occasionally found in the quartzite.

A short distance south and west of the quartzite is a ridge running a little east of north, made up mainly of granite, which presents several bold faces to the west. Near the south end and on the west side, is found upon the granite a westerly dipping fringe of conglomerate, which extends some 50 feet along the strike, as a continuous rock mass. Farther north occasional small patches of conglomerate on the northwesterly sloping granite faces, indicate that the contact follows very closely the direction of the ridge, and lies near its western base.

III. Granite.

The granite exposed on this ridge occurs in both white and reddish weathering varieties, which appear to be, however, identical in composition and age. The rock is a coarse mixture of quartz and feldspar of which orthoclase is an important part, and which occurs in Carlsbad twins up to two inches in length. Light colored mica and biotite are largely developed in the planes of shearing. The granite contains much pegmatite, both in veins and in irregular masses. From the contact with the conglomerate back as far as exposures extend, the granite is


I
Granite.
Quartz.
Inches
0 3 6 8 12
II
Granite.
Quartz.
Inches
0 3 6 9 12
III
Granite.
Quartz
Inches
0 3 6 9 12
IV
Inches
0 3 6 9 12
V
N
Upper Huronian
Lower Huronian.
Granite Gneiss.
Area represented on Large Map.
— Scale —
2 Inches = 1 Mile.
6
Republic
Michigamme River
Republic Mine
VI
About 10 feet.
A
B

Figs. I.–VI.

traversed by a rude cleavage, which has a general northwesterly direction, and so makes a large angle with the line of contact. The direction of cleavage varies between the limits of N. 40° W. and N. 60° W., and is usually represented by a multitude of planes, in which the micas only are foliated. This cleavage is more strongly developed on the western side of the exposure, near the contact, than elsewhere; and as the cleavage becomes more perfect, the large orthoclase crystals disappear.

IV. Conglomerate.

The matrix of the conglomerate varies between a somewhat micaceous quartzite and a fine grained mica-schist, and shows very distinct bands differing in color, texture, and composition. These bands are thrown into little folds, about northwesterly plunging axes; in strike they conform to the direction of the line of division between the conglomerate and the granite. In this quartzitic matrix are imbedded clearly water-rounded pebbles of quartz, granite, and of a black crystalline schist. The quartz pebbles are as a rule small, few exceeding six inches in diameter. They are of different varieties, clear, milky, brown, and blue gray quartz all being represented. All are more or less thoroughly granulated. They are of very different shapes, and within the planes of bedding, their longer axes lie in different directions. All agree in being smoothly worn and are unmistakably water-rounded.

The granite fragments vary in size from pebbles a fraction of an inch up to bowlders five feet in diameter. The larger are usually thin slabs lying with their flat sides parallel to the bedding. The foliation of the matrix often follows round the inclusions. The contacts between pebbles and matrix are exceedingly sharp; sometimes, however, where several pebbles lie close together, it is a matter of some difficulty to trace the boundary of each on the weathered surface. The distribution of pebbles is very irregular. Near the south end of the exposure they are closely packed, while the northern part of the main exposure has comparatively few. The granite of the pebbles and bowl-

ders appears to be identically the same granite as that on which the conglomerate rests. We find both the white and the red-weathering varieties represented among the pebbles of the conglomerate, and perhaps also the coarse pegmatite. Figures I and II from a sketch made to scale in the field show the appearance of the rock on the dip surface, while Fig. III, drawn to the same scale, shows the outlines of two medium-sized granite bowlders, as seen in cross section on a joint plane.

V. Contact.

At the south end of the main exposure, a nearly vertical cross joint plane on the south of which the rocks have been removed, shows the contact for eight or ten feet across the strike. The relations are represented in Fig. IV.

The conglomerate can be followed by its pebbles with great certainty. The granite below is equally unmistakable. Between the lowest pebble layer of the conglomerate and the undoubted granite, is a zone a few inches wide, that is difficult to assign with certainty to either rock. The contact otherwise is very definite and follows the dip of the conglomerate pebbles. There is no indication that the contact is not simply one of erosion. As the matrix of the conglomerate has been transformed into a crystalline schist as the result of shearing, one may easily suppose that the doubtful zone represents either recomposed granitic detritus or the broken up material of both rocks due to movement along the contact during the folding.

At the north end of the main exposure we have another natural section on a cross vertical plane, shown in Fig. VI. Here a large semi-detached mass of granite, which seems to be joined at the east end to the main mass, lies over a portion of the conglomerate. At its west end it includes a folded fragment of the conglomerate matrix four or five feet long, and two or three feet across, shown at B in the figure.

The junction between the quartz-schist and the granite is sharp, and the banding of the schist is cut at a small angle by the granite. At the east end of the granite mass, at A, a ver-

tical gash four or five inches wide, is filled with conglomerate, connecting with the conglomerate below, and tapering irregularly to a point on the upper surface of the exposure. It is clear, as Professor Van Hise has suggested, that the large mass of granite was a partly detached block of the irregular surface upon which the conglomerate was laid down, and that the sedimentary material at A and B has sifted into cracks existing in it at that time.

VI. Summary.

1. We have near Republic a conglomerate which from its relations must lie at the base of the Lower Huronian, and cannot possibly be Upper Huronian.

2. This conglomerate rests in visible contact upon granite, and is a basal conglomerate;—*i. e.*, it contains numerous waterworn fragments of the granite upon which it rests.

Henry Lloyd Smyth.

A PLEISTOCENE MANGANESE DEPOSIT NEAR GOLCONDA, NEVADA.[1]

THE LOCATION OF THE DEPOSIT.

GOLCONDA is a small settlement in northern Nevada, in the valley of the Humboldt river, on the line of the Central Pacific Railroad. A deposit of manganese ore occurs about three miles northeast of the town, on a part of the Havallah Range locally known as the Edna Mountains, and a short distance south of where the Humboldt river has cut its channel through the range. The deposit is small and of no great commercial value, but it is of interest both in the nature of the ore and in its geologic relations.

THE NATURE OF THE ORE.

The ore is a massive, black, glossy oxide of manganese with a hardness varying from 3 to 4. It is generally of a more or less porous structure, often containing cavities lined with mammillary or stalactitic forms, and it sometimes shows apparent signs of bedding. In places it is soft, earthy and pulverulent and contains angular fragments of sandstone, shale and limestone from a small fraction of an inch to several inches in diameter. Sometimes it is stained brown by iron.

The following analysis by R. N. Brackett, Chemist of the Geological Survey of Arkansas, shows the composition of a specimen of this ore dried at 110°-115° Centigrade.

Analysis of Manganese Ore from near Golconda, Nevada.

Manganese protoxide (MnO)	65.66
Oxygen (O)	10.31
Ferric oxide (Fe_2O_3)	3.32

[1] This deposit was examined by the writer while investigating the manganese resources of the United States and Canada for the Geological Survey of Arkansas, and was first described in Vol. I. of the Geological Survey of Arkansas for 1890, J. C. Branner, State Geologist, R. A. F. Penrose, Jr., Assistant Geologist.

Alumina (Al_2O_3)	0.34
Cobalt oxide (CoO)	(not determined)[1]
Lime (CaO)	3.44
Baryta (BaO)	5.65
Magnesia (MgO)	1.26
Potash (K_2O)	0.35
Soda (Na_2O)	none.
Phosphoric acid (P_2O_5)	none.
Tungstic acid (WO_3)	2.78
Silica (SiO_2)	1.70
Water and organic matter	4.16
	98.97

Metallic manganese	50.85
Metallic iron	2.32
Metallic tungsten	2.20

It will be seen by the analysis that the ore is an impure oxide of manganese, being possibly a mixture of the peroxide and sesquioxide, though the impurities obscure its true nature. The most remarkable feature of the ore is the considerable amount of tungstic acid present, comprising 2.78 per cent of the ore and corresponding to 2.20 per cent of metallic tungsten. The form in which the tungsten exists in the ore is uncertain. It is possible that it may exist as a tungstate of manganese or iron, or of both, or perhaps of one of the other bases present. It may either have been deposited from solution with the manganese, or it may have been brought in as detritus from an outside source during the deposition of the ore, in the same way as the fragments of rock were brought into the deposit.

Though from a mineralogical standpoint the ore is impure, yet for commercial purposes the analysis shows a good grade of manganese ore, and the presence of the tungsten would give additional value to the ore in the manufacture of certain kinds of hard steel.

THE NATURE OF THE DEPOSIT.

The ore occurs as a lenticular deposit imbedded in a soft white or buff colored calcareous tufa which contains fragments of sandstone, shale and massive limestone similar to those found

[1] There is more than a trace of cobalt present but the amount was not determined.

in the ore and often in sufficient quantities to form a breccia. This material composes a small knoll on the lower slope of the mountain, and lies on the upturned edges of underlying shale. The association of the manganese and the tufa is shown in Figure 1, while the relation of the deposit as a whole to the Edna Mountains is shown in Figure 2. The first figure represents the small knoll on the left hand side of the second figure.

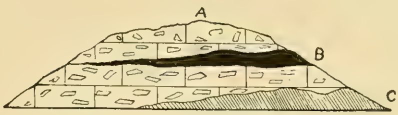


FIGURE 1.—*Section through the Golconda manganese deposit.*

A. Calcareous tufa. B. Manganese ore. C. Shale.

Horizontal scale: 1 inch = 125 feet. Vertical scale: 1 inch = 80 feet.

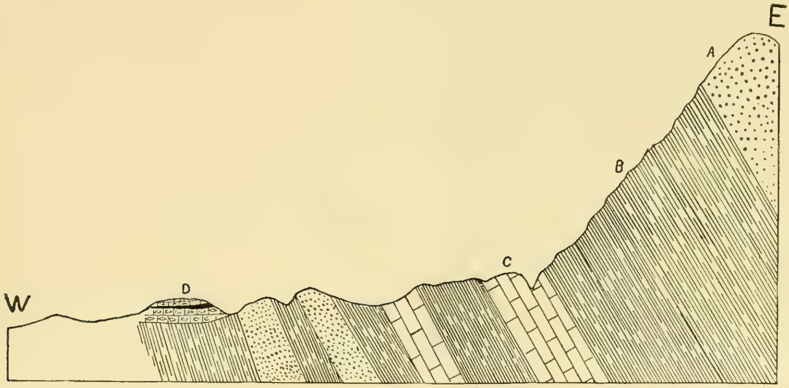


FIGURE 2.—*Section showing the relation of the Golconda manganese deposit to the rocks of the Edna Mountains.*

A. Quartzite. B. Shale. C. Limestone. D. Manganese-bearing deposit.

Horizontal scale: 1 inch = 500 feet. Vertical scale: 1 inch = 300 feet. (Both of these scales are only approximations.)

The outcrop of the ore bed appears as a horizontal black band along the side of the knoll facing the mountains, and is very variable in thickness, in some places being represented only as a black line in the white material enclosing it and in others

widening to a maximum, where exposed, of three and a half feet. On the west slope of the knoll the ore bed is not seen at all, the only trace of it being an occasional black stain or dendrites in the limestone along the line where it should outcrop if it extended through to this side. The bed also thins out to the north and south, the whole length of the outcrop being only about 400 feet. East of the outcrop of the ore, the knoll is cut sharply off, as shown in Figure 2, by a rocky area which separates it from the mountains. It will thus be seen that the amount of ore here is limited, and it is probable that the area underlain by it does not cover more than a few acres.

Beneath the ore bed, as seen in one of the small pits that have been made on the deposit, the calcareous material is soft and partakes of the nature of a marl, while above, it is often much harder and has in many places become coarsely crystalline. The crystillization seems to have taken place in spots in the bed, and frequently bodies of crystalline material are surrounded by, and blend into a massive and softer tufa of the same composition.

The fragments of sandstone, shale and gray limestone found in this deposit are of the same nature as the beds of those rocks which comprise the mountain to the east and are undoubtedly derived from them. The pieces of limestone are so markedly different from the calcareous bed enclosing them that they cannot be confounded with it. The rock fragments are of unequal distribution in the deposit, both laterally and vertically, sometimes composing almost half of it, and sometimes being almost entirely absent. They vary from a fraction of an inch to several inches in diameter and are indiscriminately mixed.

The age of the rocks composing the part of the Havallah Range lying east of the manganese deposit is represented as Star Peak Triassic on the map accompanying the Survey of the Fortieth Parallel.[1] As shown in the section given above they are

[1] U. S. Geol. Exploration of the Fortieth Parallel; Clarence King, Geologist in charge; Vol. I., Systematic Geology, map III., Pre-Mesozoic and Mesozoic Exposures. See also report of Arnold Hague, Vol. II., Descriptive Geology, page 680.

composed of sandstones, shales and limestones dipping at steep angles. The upturned edges of the rocks are well exposed from the summit of the mountain to its base, where they are covered by the small knoll or mound containing the manganese deposit.

The crest of the mountain is composed of a quartzite which is of a dark gray color, spotted with brown specks, of a granular structure, very hard and cut by numerous quartz veins. The lower beds of quartzite on the slopes resemble this one in all respects except that they show less trace of their original sandy structure and are more vitreous. The larger part of the slope of the mountain is composed of a more or less slaty shale. It is of a gray or purple color, contains large quantities of thin flakes of mica, has a wavy, undulating structure and in some places grades almost into a micaceous or talcose schist. The lower beds of shale are much thinner than this one, and in some places resemble it in general appearance, while in others they are more calcareous and blend into limestone. The shale which underlies the knoll containing the manganese (see figures) is of a light yellow color on its surface exposure, and is made up of thin friable laminæ. The limestone beds shown in Figure 2 are all of much the same character; they are of a light or dark gray color, sometimes with a reddish tinge, generally massive, though occasionally showing a tendency to a semi-crystalline structure, and are frequently cut by veins of white crystalline calcite.

THE ORIGIN OF THE DEPOSIT.

The Golconda manganese deposit is in the arid region lying between the Rocky Mountains and the Sierra Nevada, and known as the "Great Basin." Parts of this region, as is well-known, were, in Pleistocene, or Quaternary, times covered by several large inland bodies of water, of which lakes Bonneville and Lahontan, described respectively by G. K. Gilbert[1] and I. C. Russell,[2] were the largest. In subsequent times these were

[1] Lake Bonneville, Monograph U. S. Geological Survey, No. I., 1890.

[2] Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885.

mostly dried up, and the only remains of them now are a series of much smaller lakes, occupying hollows in the bottoms of the old lake basins. Great Salt Lake is the modern representative of Lake Bonneville; and Tahoe, Winnemucca, Pyramid and other lakes occupy the basin of Lake Lahontan.

The region about the manganese deposit is on the eastern edge of the area defined by Mr. Russell as the ancient bed of Lake Lahontan, and occupies a position at the head of what was once a small bay protruding about fifteen miles up what is now the valley of the Humboldt River. Mr. Russell,[1] in speaking of the lakes which formerly existed in the Great Basin, says: "Some of these old lakes had outlets to the sea, and were the sources of considerable rivers, others discharged into sister lakes; a considerable number, however, did not rise high enough to find an outlet, but were entirely inclosed, as is the case with the Dead Sea, the Caspian, and many of the lakes of the Far West at the present time." Lake Lahontan did not overflow, and, therefore, the mineral matter brought to it in solution by tributary waters constantly increased in quantity; while the gradual evaporation of the lake steadily concentrated these mineral solutions until they arrived at a state of supersaturation, and were deposited as chemical precipitates. These were, according to Mr. Russell, largely of a calcareous nature, and were laid down as fringes on the margin of the lake at successive stages of evaporation. They are found now at different levels on the old lake border, and mark the ancient shore lines. Mr. Russell has divided them into three classes of "tufas," differing considerably in physical character, and deposited at different levels during the desiccation of the lake. He has named them in the order of their chronological succession, "lithoid," "thinolitic," and "dendritic" tufas. From the analogy of the samples of tufa collected by the writer at the manganese deposit with the description of lithoid tufa given by Mr. Russell, and from the position that the deposit occupies in the old Lake Basin, it is probable that

[1] Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885, page 6.

the calcareous material with which the Golconda manganese deposit is interbedded represents the lithoid tufa of Russell, and that the manganese itself is a local deposit not necessarily characteristic of the variety of tufa with which it is associated. In other words, the deposit represents a lenticular bed of manganese ore interstratified with a calcareous sediment, the latter having been chemically deposited from supersaturated lake waters. It will be seen in Fig. 2 that the manganese deposit occupies a basin in this tufa, that the basin was originally cut off on the east side by the rocks that formed the old shore line, and that it was bounded on its west side by the outer edge of the tufa terrace. Between these limits it extended a short distance up and down the lake shore. This position, as well as the nature of the ore, both tend to show that the bed was originally laid down as a shallow water deposit and subsequently covered over by a tufa similar to that which underlies it.

It seems possible that the origin of the ore deposit was a local accumulation of manganese precipitated from spring waters. In support of this supposition it may be stated that at the town of Golconda there are, at the present time, a series of hot springs depositing a sinter highly charged with oxide of manganese. The source of this manganese in the spring waters may have been in the igneous rocks which cover large areas in the region in question, and give strong reactions for manganese. Another possible source of supply may have been in the stratified rocks already described as forming the mass of the mountain on the slope of which the deposit is situated, as both the quartzite and the limestone contain small quantities of manganese. The igneous rocks, however, contain a larger percentage of this material than the other rocks.

As regards the mode of precipitation of the manganese, it is not probable that the ore was deposited simply by the gradual desiccation of the lake waters, as was the case with the lithoid tufa enclosing it, since, if this had been so, a far more general distribution of manganese than is seen in the tufa of the Lahontan basin would be expected. It seems more probable that the

deposit was due to a local precipitation brought on by an excess of manganese in spring waters in the locality in question, and that the cause of its accumulation was the accidental formation of a suitable basin in the tufa. This basin may either have been closed or may have had an outlet into the lake. When the spring waters reached the surface they were probably retained, at least temporarily, in the basin, long enough to allow the oxidation of the metalliferous solution and the precipitation of oxide or carbonate of manganese,[1] thus causing a local accumulation of ore; whereas, if the spring water had flowed directly into the lake, its contents of manganese would have been scattered over a vast area, and would not have accumulated anywhere in deposits of noticeable size. The rock fragments in the ore and tufa represent detritus from the mountain side carried down during the deposition of the beds.

The deposition of manganese by spring waters elsewhere than in the case in question, though in limited quantities, is not an unusual occurrence. The Hot Springs of Arkansas deposit a calcareous sinter often heavily impregnated by manganese. A hot spring near the Cape of Good Hope,[2] with a temperature of 110° Fahrenheit, deposits oxide of manganese in its discharge channel. A mineral spring in the house of the Russian Crown, at Carlsbad,[3] with a temperature of 68° Fahrenheit, also forms manganiferous deposits. The springs at Luxeuil,[4] as well as the waters in some of the mines at Freyberg,[5] also form manganiferous sediments. These deposits, however, are all very small and are simply mentioned to show the frequent occurrence of manganese deposited by springs. Cases where a black incrustation of oxide of manganese is deposited by rivers and creeks on the rocks and pebbles in their courses are of common occurrence.

R. A. F. PENROSE, JR.

[1] If the carbonate was precipitated, it was later converted by oxidation into its present oxide form.

[2] Townsend, l' Institut., 1844, No. 529. (Bischof.)

[3] Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

[4] Braconnot, Ann. de Chim. et de Phys., Vol. 18, p. 221. (Bischof.)

[5] Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

Studies for Students.

THE ELEMENTS OF THE GEOLOGICAL TIME-SCALE.

The formations, as we find them classified in this time-scale, are arbitrarily limited and classified, but back of this arbitrary classification, certain grand events in the history of the earth are indistinctly seen. The primary units of the classification are called systems. Beginning at the base of the fossil-bearing series resting upon either Archæan or rocks of uncertain age there are first, the (1) Cambrian system of Sedgwick, restricted and also expanded as the result of later investigation. Second, the Silurian system of Murchison, divided into two, the lower Silurian which, to avoid confusion, and to give definiteness to the nomenclature has been named (2) Ordovician, by Lapworth, and the upper Silurian, for which we will retain, thus restricted, the name (3) Silurian. The fourth system, (4) Devonian, was proposed by Murchison and Sedgwick. The (5) Carboniferous system follows, which was early defined in Geology, but it is not clear who first proposed the name early applied to the coal-bearing rocks. Above this is the (6) Triassic system of Bronn, followed by the (7) Jurassic system of Brongniart. To the next system the name (8) Cretaceous was applied by Fitton. The next system still retains the name (9) Tertiary, of Cuvier and Brongniart, and is terminated by the (10) Quaternary system, whose name was introduced by Morlot. Tertiary and Quaternary were applied on the plan of Lehmann's classification which, in other respects in the course of events, has dropped out of the nomenclature.

Without explaining how the series of stratified rocks come to be divided into these particular ten systems, it may be said that their retention is due mainly to the relatively sharp boundaries

which each system exhibits in its typical locality. The systems thus serve as known and definite standards of comparison in the construction of the time-scale, as the dominance of nations or the dominance of the dynasties in each serve as time standards for the discussion of ancient human history. As the period of each dynasty in ancient history is marked by continuity in the successive steps of progress of the country, of the acts of the people and of the forms of government, and the change of dynasties is marked by a breaking of this continuity, by revolutions and readjustment of affairs, so in geological history the grand systems represent periods of continuity of deposition for the regions in which they were formed, separated from one another by grand *revolutions* interrupting the regularity of deposition, disturbing by folding, faulting and sometimes metamorphosing the older strata upon which the following strata rest unconformably and form the beginnings of a new system.

Geological revolutions were not universal for the whole earth; from which it results that these typical systems and their classification are not equally applicable to the formations of all lands. It is important also to note that the geological revolution was not a sudden catastrophe but the culmination of slowly progressing disturbances bringing the surface of the region concerned ultimately above the level of the ocean, the ocean level being a pivotal point in geological rock formation. The area whose surface is below the sea level may be accumulating deposits and making rocks, but so soon as the same region is lifted above the surface it becomes a region of erosion, destruction and degradation. Whenever, therefore, in the oscillations of level any particular part of a continental mass of the earth's crust passes permanently, or for a long geological period of time, above the sea level, a great event in geological history has culminated. In case the elevation is only temporary the event is marked by unconformity, or a break in the continuity of the formations; when it is permanent the geological record for that region ceases except so far as fresh water deposits in lakes may continue independent records. Hence it is that these periods of revolution are of such import-

ance in the history of the continents, and constitute the most satisfactory marks for the primary classification of geological history.

The natural geological system is a continuous series of conformable strata. A geological revolution is expressed by unconformity and more or less disturbance and displacement of the strata from their original position. The grander revolutions are also recorded in the permanent elevation of mountain masses or extensive continental areas, above the level of the sea and thus out of the reach of later strata accumulation. The most widely recognized revolution in geological time, since the close of the Archæan, separates the Carboniferous from the Triassic system. In American classification, following Dana's usage, it may be called the Appalachian revolution. It terminated the series of formations which, with only minor interruptions, had been continuously accumulating in the Appalachian basin from the early Cambrian period onward. It left above the sea level not only all the Appalachian region but the great part of the eastern half of the continent, extending westward beyond the Mississippi river to a line running irregularly from western Minnesota to Texas. This revolution produced the Allegheny mountains, and those flexings and faultings which are still recognized in the line of lesser ridges extending from Pennsylvania to Georgia. In England, Northern Europe and Northern Asia like disturbances took place at the same general period of time. In Australia, Southern Africa and South America, the indications are that the revolution was not so extensive, if it took place at all at the same time. The probabilities are that while it was almost universal for the northern hemisphere it was mainly confined to this half of the earth. The Appalachian revolution was not limited to a brief geological period but beginning near the close of the coal measures of the east it did not become effective in the region of Kansas and Nebraska till the close of the Permian. The wide extent of the disturbance of strata and consequently of records at this point in the time-scale has led to making here a primary dividing point of the scale, marking off Palæozoic time.

Several lesser, more or less local, revolutions have left their permanent mark in the grander structure of the rocks or in conspicuous geographical features of the restricted region of the continental area. The first of these was the Green mountain revolution which separated the (Lower Silurian) Ordovician from the (Upper Silurian) Silurian, for the eastern part of North America. The elevation, disturbance and metamorphism of the rocks of the Green Mountains stand forth as monuments of this event. The revolution is not sharply distinguishable in the rocks of the more southern or western regions. The second of these lesser revolutions is expressed most sharply in elevation and unconformity terminating the Devonian formations of Maine, New Brunswick and Nova Scotia, and may therefore be called the Acadian revolution. In the continental interior it may be indicated by the remarkable thinning out of the Devonian rocks toward the southwestward. In Tennessee, Alabama and Arkansas they are represented by a thin sheet of black shale, a few feet thick, or by but little more than a line of separation between the rocks of the Silurian below and the Carboniferous beds resting scarcely unconformably upon them. This seems to indicate an elevation of the region still further south toward the close of the Devonian, sufficient to produce extensive erosion, uncovering the Lower Silurian rocks which were again depressed to receive the marine deposits of the early Carboniferous upon their eroded surfaces.

The Appalachian revolution closed the Palæozoic time and left the great part of the eastern half of the continent above sea-level. It forms the natural interval between the Carboniferous and the overlying system, whatever that may be. Its characteristics have already been described.

The Palisade revolution, along the eastern border of the continent, marks the division between the Jura-Triassic part of the Mesozoic time and its closing Cretaceous age. It is expressed by the trap ridges in the Connecticut valley, the Palisades and other similar tracts distributed inside the coast from Nova Scotia to North Carolina, and by the uptilting and in some cases fault-

ing of the underlying red sandstone and shale, and the resulting unconformity with the succeeding formations. The evidences of the revolution are not widely extended nor is the time relation of the termination of the revolution sharply defined, but it is sufficiently so to form a natural boundary line separating the Jura-Trias from the Cretaceous. After this point of time there occurred nothing in the eastern half of the continent which deserves the name or rank of a geological revolution. The western part of the continent is conspicuous for its grand geological construction after the Triassic at least; along the coast the Sierra Nevada revolution marked the same general interval of time recorded by the Palisade revolution of the east. These events on the opposite borders of the continent are alike at least in preceding the Cretaceous and in terminating the formations which are of Jura-Triassic age.

The Rocky Mountain revolution, which resulted in the elevation and disturbance of the rocks in the region of the Rocky Mountains, and extended from them to the border ranges, is distributed along the time from the close of the Cretaceous to the Miocene, or possibly later. It is altogether probable that the actual length of time, taken in the elevation, tilting and disturbance of strata after the last marine deposits of the pre-Laramie formations, which resulted in the permanent adding to the continent of its western third, was not longer than that consumed in the various events terminating the Palæozoic, and making into permanent land the great mass of the eastern half of the continent. This Rocky Mountain revolution resembles the Appalachian revolution, in extending over and affecting a large area of the continent, in its general upward-lifting of that area, which process extended over a long period of time, and in the great accumulation of coal or lignite which was associated with the gradual emergence of the continental mass above the sea-level.

Another feature in which the two revolutions resemble each other is found in the wide extent of the disturbances recorded. The elevation of the mountain ranges from the Pyrenees east-

ward to the Himalayas, and to the islands beyond, took place chronologically at the same general period, and that this series of disturbances may have affected the whole of the northern hemisphere is further suggested by the occurrence of gigantic erratic blocks of granite in the midst of Eocene strata in the neighborhood of Vienna and other places. Vezien (Rev. Sci. XI., p. 171, 1877) has suggested that an ice-age is indicated by these events.

This Rocky Mountain revolution marks the period of the second great break in the life of the geological ages. The Mesozoic time began with the close of the Appalachian revolution, and closed with the elevation of the Cretaceous beds above ocean-level. In our classification the division line between the Cretaceous and Tertiary was arbitrarily placed at the top of the chalk formations conspicuously developed on both sides of the British Channel. The difficulty American geologists have had in drawing the precise line to separate the Mesozoic from the Cenozoic has resulted from the change of the character of life in the beds in the western interior from marine to brackish, fresh-water and land types. This change was incident to the Rocky Mountain revolution, which had already begun, and was slowly lifting the whole region while the Laramie sediments were being laid down. Several stages may be marked in this grand revolution, but the facts connected with them are not so well-developed as to serve for general purposes of classification of the time scale.

At the close of the Miocene, a great outflow of lava in the northwestern part of the United States took place, and continued with interruptions through the Tertiary into the Quaternary time. About the Columbia River, where it cuts through the Cascade range, the basalt is over three thousand feet thick, and the outflows cover a vast extent of territory, estimated at 150,000 square miles. This was incident to the vast earth disturbance which raised to the amount of at least five thousand feet a large part of the western half of the continent.

There was, still later, a revolution which has left little record in the way of disturbance or discordance of strata, but was of

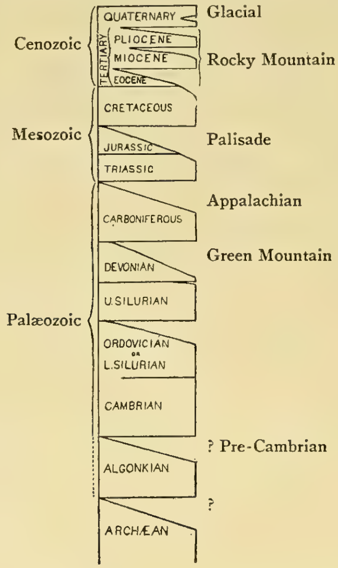
particular importance in life-history, as it introduced the recent period, or the age of man. This is the combination of events marking the glacial epoch. In general, it consisted geologically of oscillations of the northern lands for the northern hemisphere, and was associated with the accumulation of ice upon the surface and its continuance as a great ice-sheet for a long period of time. Some of the more accurate estimates of the length of geological time are based upon the rate of erosion or gorge-cutting by rivers, and the period so measured dates back to the last uncovering of the river channels coincident with the northward withdrawal of the ice-sheet. Standard examples are the estimates of the time required to cut the Niagara River gorge, and the retreat of the falls of St. Anthony from Fort Snelling to their present position, as beautifully elaborated in Winchell's Report on the Geology of Minnesota, vol. 2.

The above revolutions are selected, not as the only revolutions interrupting the regular course of sedimentary formation of stratified rocks, but as chief examples of such interruptions in the North American scale. All along the course of geological time there are evidences to show that there were constant oscillations of the relations between land and ocean-level, and at some localities these oscillations were passing across the datum plane of the ocean surface. Wherever this happened, on one side rocks were forming, and on the other erosion and degradation obliterating them as time-records. The Appalachian and the Rocky Mountain revolutions constitute the two grander revolutions. The first closed the Palæozoic life Period, the fossils being chiefly marine until the Devonian, and being associated with marine forms up to the close of the Carboniferous. The deposits are distributed across the continent, with local interruptions. After the Appalachian revolution the eastern half of the continent, except its Atlantic and Gulf borders, became permanently above the sea-level.

The period between the Appalachian and Rocky Mountain revolutions is the period of the Mesozoic life. In the faunas and floras of this period, land and fresh-water species take a promi-

nent part. The marine life is distributed over the western half of the continent and along a narrow line of formations on the Atlantic and Gulf borders. After the beginning of the Rocky Mountain revolution, the deposits of marine origin and their faunas were distributed on the marine borders of the continent as it now is, and fresh-water and land deposits were accumulated over the plains and plateaus of the western half (with few exceptions) of the continent.

Thus the grander revolutions recorded in the development of the American continent break up the geological time-scale expressed in the systems of stratified rocks into a few natural subdivisions, as may be illustrated by the following diagram:



In the use of the time-scale for the study of the history of organisms, the places marked by the revolution are those in which are found the grander interruptions to the continuity of the record. They may represent periods of great relative magnitude. They do represent periods of marked change in the faunas and floras over extensive regions. Between the grander intervals of revolution the records of life-history are relatively

continuous. There were series of successive faunas or even sub-faunas, in which were expressed the general features of the evolution of life on the globe. The species preserved and known present but a very imperfect representation of the species that were living; but of those preserved in one formation there are generally found in the succeeding formations representatives of the same or closely allied genera; so that for the kinds of organisms whose remains are best preserved the record is fairly continuous for the grander rock-systems in terms of the generic, and in some cases of the specific characters.

While the conditions of deposition for a particular region remained relatively constant and uniform, the strata were accumulated in successive beds one upon another, and then the thickness of the deposits of the same kind, with proportionate thickness for deposits of different kinds, constitute a scale of definite time value; a foot of deposit representing a period of time, and the relative time-separation for two faunas would be represented by the thickness of the strata between them. It was on this principle that the time-ratios of Dana were estimated. The maximum thickness of the known strata of each geological system was taken. The limestones were assumed to represent five times the time-value that is represented by the other sedimentary deposits per foot; or in other words, every foot of limestone was estimated as equivalent to five feet of other sedimentary deposits in making up the time-ratios. On this principle Dana estimated the time-ratio for the several geological periods to be as follows:

Quaternary - - -	¼	Cenozoic 1.
Tertiary - - -	¾	
Cretaceous - - -	1	Mesozoic 3 +.
Jurassic - - -	1¼	
Triassic - - -	1	
Carboniferous - -	2	Palæozoic 12 +.
Devonian - - -	2	
Silurian (Upper) -	1¼	
Ordovician (Lower Silurian)	6	
Potsdam - - -	1	

Ward, in the fifth annual report of the United States Geological survey, has proposed to adjust these proportions as follows:

Quaternary-Recent - -	1
Miocene-Pliocene - -	1
Eocene - - - -	1
Cretaceous - - -	1
Jura-Trias - - -	1
Permo-Carboniferous -	1
Devonian - - -	1
Silurian - - -	1
Cambrian - - -	1

thus forming nine divisions of equal length.

Since Dana's estimate additions have been made to the known thickness of the Cambrian rocks of North America, which should lengthen the Cambrian ratio to 5 in the above table, and duplications of thickness due to confusion in regard to the Quebec group may reduce the Ordovician (Lower Silurian) to 5, and the Cretaceous ratio may be somewhat enlarged. The Tertiary estimate in Dana's ratios assumes the thickness to be of less (½) time-value because of the increased rate of deposition due to transportation of rivers. This and many other factors enter in to complicate the time-value of thickness of strata; but it must be granted that the thickness of the sediments is the prime factor in determining these time-values of the geological scale. However, the conditions of deposition, the fineness or coarseness of the clastic fragments, the abundance or rarity of supply of materials and other variable conditions must be taken into consideration in an accurate reduction of thickness of strata into length of time. Errors, also, whose value is almost impossible of estimation, arise from the intervals between strata, particularly those where unconformity exists.

After all these uncertainties are weighed the time-ratios formed on this general basis are of great importance in studying the history of organisms, and the value of accuracy in the time-scale is a sufficient reason for calling attention to the points in which greater

accuracy may be attained by further investigation. It is doubtful if it is possible with our present knowledge to reach an estimate in years or centuries, of the actual length of geological time, which is within 100 or perhaps 200 per cent. of the truth. We may accept Dana's estimate of at least 48,000,000 of years, or Giekie's of from 100,000,000 to 680,000,000. We find at one extreme the ancient theory of 6,000 years and at the other McGee's possible maximum of 7,000,000,000 years.

The rate of accumulation of sediment over the bottom of the sea may vary between the limits of one foot in 730 years and one foot in 6,800 years, as pointed out by Geikie, the figures being based upon the estimated proportion between the annual discharge of sediment in cubic feet and the area of river basins in square miles, in the case of the rivers Po and Danube. The estimate of 680,000,000 of years, quoted above, is dependent upon the assumption that the total thickness (maximum) for the sedimentary deposits is not less than 100,000 feet, and that the average rate of accumulation was not more rapid than that now going on at the mouth of the Danube, based upon Bischof's determination of the amount of sediment and matter in solution in the Danube at Vienna. It may be a query worth considering whether the estimates based upon the examination of the amount of suspended and dissolved matter in river water are not likely to err in the direction of too small amount of matter by reason of the abnormal precipitation along the course of the river incident to the presence of salts and acids put into the river by man. If the rate of the river Po were taken the length of time would be 73,000,000 of years instead of 680,000,000.

The actual length of time in years, however, is of less importance to the geologist than the relative length of time for each of the ages, and these latter, the time-ratios of Dana, are clearly deducible from the physical thickness and size of constituent particles of sedimentary rocks. Relative thickness is certainly one of the elements in the determination of the time values of the geological formation, and the fields for investigation along which greater accuracy is to be reached cover the problems of

the rate of accumulation of muds, sands and pebble beds, and of the formation of limestones, in relation to each other and under varying conditions, and the detection of the marks in the strata recording the conditions incident to the varying rates of accumulation. Until the evidence is fuller the time-ratios of Dana may be adopted as expressing approximate values for the various geological ages.

In all these studies in which the geological time-scale is applied to the evolution of the earth and its inhabitants, the time concerned is not human chronology but is what may be called *geochronology*. For this purpose we need a standard time-unit or *geochrone*. The geochrone applied in Dana's time-ratios appears to be 8,000 feet of sedimentary deposits, as in the Potsdam, (7000 feet sediments and 200 limestone). Something more definite is needed and one in which the equivalents in different kinds of deposit and in different regions can be studied and compared with some approach to accuracy. The Eocene period, as expressed in the gulf states on both sides of the Mississippi river, might be selected as a convenient and practicable standard for this purpose. Humphrey and Abbot's elaborate studies of the Mississippi river furnish minute data for comparison with recent conditions. There are 3,000 feet of marine beds referred to the Eocene in southern Europe. The Eocene or early Tertiary fresh-water beds reach a thickness of at least 10,000 feet. The Tertiary beds in Liguria are estimated to reach the thickness of 23,600 feet. If for the present we assume the Eocene geochrone to be equivalent to the maximum deposit of 3,000 feet of fragmental sediment on the edge of the continent, using Dana's estimates of time-ratios with some modifications, and adopting the term Eocene as the American students of marine Eocene apply it, the following standard time-scale for geochronology is constructed. The geochrone in this scale is the period represented by the Eocene, as understood in North America to include the marine deposits and their faunas, from the close of the Cretaceous to the top of the Vicksburg or white limestone of Smith and Johnston, 1,700 feet of which are seen in Alabama. In England it

may include the Oligocene to the top of the Hempstead beds. I realize that such a proposition furnishes many points for dispute. The scale is open for correction, and the standard may be defined with greater precision. But it is offered as a working hypothesis, to aid and stimulate investigation.

Such a standard time-scale of geochronology, on the basis of the Eocene period for a time-unit or geochrone would read as follows:

Recent, Quaternary	1	
Pliocene, Miocene	1	= 3.
Eocene	1	
Cretaceous	4	
Jurassic	3	= 9.
Triassic	2	
Carboniferous	6	
Devonian	5	
Up. Silurian	4	= 45.
Low. Silurian or Ordovician	15	
Cambrian	15	

The proximity of the Eocene of the Gulf border to continental conditions now in operation, the abundance of its marine fauna for comparison with like faunas of earlier or later age and of the same or different habitats, and its inclusion of traces of land-life for correlation with other conditions, and, in general, the wide distribution of available Eocene deposits and faunas for comparative study, are reasons for calling attention of investigators to this particular field for minute investigation in perfecting the geological time-scale.

HENRY S. WILLIAMS.

EDITORIALS.

THE United States Geological Survey is to be congratulated upon the appearance of the first atlas sheets of the geological map of the United States which, although still considered as preliminary to the regular edition, may be taken as essentially finished, and as embodying the chief features which will characterize the completed work. Each atlas consists of one portion of the whole map printed in four ways: one presenting the topography by itself; one, the areal geology; another, the geological structure by means of cross sections, and a fourth, the features of economic importance. Accompanying these are sheets of text, one of which explains certain elementary concepts of the science and defines the sense in which some of the more common terms are to be employed throughout this series of publications. The text describing the special area surveyed is admirably prepared to set forth in a concise manner the leading features of the geology and of the economic resources. It is prefaced in some cases by a general sketch of the region immediately surrounding the area published, which aids materially the comprehension of the more local geology. In one instance, however, the sketch embraces nearly the whole eastern portion of the United States, which seems unnecessary since, we assume, it is not the intention of the Survey to do away with the publication of its monographs and bulletins, where the full results of the several investigations should appear. Otherwise, the text accompanying the atlas sheets would be insufficient.

The sheets finished are from widely separated parts of the country: the Hawley sheet in Massachusetts, the geology of which is by Professor B. K. Emerson; the Kingston sheet in Tennessee, the geology by Mr. C. Willard Hayes, assisted by

Mr. M. R. Campbell; the Lassen Peak sheet and Sacramento sheet in California, the geology of the former by Mr. J. S. Diller, that of the latter by Mr. W. Lindgren. The character of the geology is equally diverse, embracing highly metamorphosed sediments in the first case, slightly modified strata in the second, and in the last two, metamorphosed igneous and sedimentary rocks associated with volcanic lavas. We notice with satisfaction the prominence given to economic features as well as the clear statement of facts regarding the dates at which the work was prosecuted, and the investigators who are to be credited with the work, two essential elements in forming a judgment as to the character of the results.

While the atlas sheets are alike in size they differ in scale from 1-250,000 to 1-62,500. The relative areas, however, are shown upon an index map on the cover of the atlas. These differences of scale are desirable because of the variable importance of the different parts of the country, and the variability in the character of the geology, which may be best represented upon maps of different scales. Such flexibility is a distinct advantage. The success of the effort to introduce greater elasticity into the method of coloring geological formations will be variously estimated. It is not possible to form a fair opinion of the merits of the system from the few examples of it furnished by the four atlas sheets already finished. But it would seem that the prominence accorded to pattern in the system, by making it a basis for the distinction of the main subdivisions of rocks: sedimentary, igneous and metamorphic, has been nullified by the lithographer, who has succeeded so admirably in reducing the lining to a mechanical minimum that the detection and recognition of patterns is a test of eyesight. We appreciate the difficulties attending the application of any comprehensive scheme of colors to so large and diversified a series of atlas sheets as that which will constitute the map of the United States, and look upon the efforts so far made as having advanced the problem without completely solving it. In the meantime the results already obtained by the geologists of the Survey in many

parts of the country should be published without waiting longer for a perfect method of coloring to be devised. J. P. I.

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Do oscillations of the crust progress by waves? Or are they limited to non-progressive vertical elevations and depressions, or to oblique thrusts and resiliences? Or are there both stationary and progressive oscillations?

The subject does not seem to have received much definite investigation, although it finds incidental expression here and there in geological literature. It is clear, however, that a determination of the stationary or progressive character of crust oscillations must have an important bearing upon the various hypotheses that concern the relations of the earth's crust to its interior. It is obvious that preliminary to a study of these problems there must be dismissed from consideration those merely apparent oscillations of the crust that are in reality but variations of the sea level. It seems quite certain, however, that when these are eliminated there remain a large class of true crustal movements. The elucidation of these is extremely difficult and would be greatly aided if it were known whether they are local or migratory, and, if migratory, whether there are any general laws governing the direction of their movements, their rate of progress, etc. If migratory, do these undulations radiate from a point of origin in all directions, like the wave circles induced upon a liquid surface, or do they, like tidal waves, creep forward in a single direction?

If we combine by free hypothesis the elevations and depressions of the Pacific coast during the Pliocene and Pleistocene times with those of the Mississippi basin and of the Atlantic coast, it is not difficult to construct a procession of elevations and depressions creeping successively across the continent. Is such a synthesis supported by any close definite data indicating progressive undulation, or is it merely an artificial combination of selected data thrown into order arbitrarily at the suggestion of an hypothesis? This illustrates a class of questions whose solution presumably leads back to crustal and sub-crustal agencies.

Another class presumably involve superficial loading and unloading, as, for example, the accumulation and dissipation of continental glaciers. These are less radical in nature and less general in applicability, but perhaps offer greater hopes of early solution. There are few problems in geology more difficult of satisfactory elucidation, even by hypothesis, than the moderate but widespread oscillations of the earth's crust. The problem of mountain building, though more obtrusive, seems really less difficult than that of plateau formation, and that of plateau formation, in turn, less unpromising than that of the common widespread crustal oscillations.

The writer has become interested in these questions in connection with some studies of the earth's crust and interior, and would welcome contributions to the subject either for publication or for personal information. T. C. C.

Reviews.

Monographs of the U. S. Geological Survey, vol. XVII. The Flora of the Dakota Group. A posthumous work by Leo Lesquereux. Edited by F. H. Knowlton. 256 pp., 66 plates. Washington, 1892.

The posthumous issue of this product of many years of labor, including some of the best work of one who for many years was distinguished as the highest authority in American paleobotany, is a matter of great interest to both paleontologists and biologists, since it renders the plant remains of the Dakota group, one of the oldest dicotyledon-bearing terranes, the most completely-elaborated and best-known flora, perhaps without exception, of any restricted formation in the world. Within its two hundred and fifty-six quarto pages, four hundred and sixty species are described, or, in the case of those concerning which no new observations had been made since the publication of his "*Cretaceous Flora*" and "*Cretaceous and Tertiary Floras*," enumerated with references to his earlier works. The drawings, a considerable number of which were unfinished at the time of the author's death, occupy sixty-six plates.

Of the flora, as a whole, over ninety per cent. are dicotyledons, one and three-tenths per cent. ferns, three and one-half per cent. conifers, and two and one-half per cent. cycads. In this overwhelmingly dicotyledonous flora, most of our American living tree-families have their representatives. While going over the descriptions and figures it will seem to some readers that the number of species, and particularly of varieties, is, in some instances, too great, there being for example, four varieties of *Salix proteæfolia*, seven of *Viburnum Lesquereuxii*, and fifteen of *Betulites Westii*, especially since we are left to infer in the latter case that all have the same rather indefinite habitat, "Ellsworth County, Kansas." But, while it is probably true that some of the variations do not vary more than the leaves on a single tree, still it should be borne in mind that that period in the history of the dicotyledons, soon after their first appearance in the Cretaceous, was one of immense diversity of form and great modification of character; and, although, as Professor

Lesquereux himself suggested, their differentiation might, under other circumstances, be "hazardous," yet the discrimination of the forms furnishes a better paleontological basis for the interpretation of modern types, as well as a higher degree of definition, for the use of paleontological stratigraphy.

At the close of the memoir, the broad range of the author's knowledge and paleobotanical experience is well shown in some thirty pages, devoted to an "Analysis" of the flora of the group. From this analysis, which is of great value to the biological paleontologist, he reaches the conclusions that, although but one-fourteenth of the species found in the Dakota group are also found in the Atane beds of Greenland, yet, considering the remoteness of the regions, the close relationship of the floras, and the difference in latitude, and, perhaps, in soil, the proofs are "really conclusive" of the synchronism of the two formations; "that most of the types of the arborescent flora of North America were present in that of the Dakota group, and that most of them had left remains of allied specific or generic forms in the intermediate periods," so that the flora of this continent is indigenous; and that "all the plants of the American Cenomanian, except those of Ficus and Cycads," which, he explains, may be omitted, "might find a congenial climate in the United States between 30° and 40° of latitude," a continued uniformity of climate, causing "the preservation of the original types of the flora, subjected to some modification of their original characters, without destroying them or forcing their removal by the introduction of strange or exotic forms."

Although a great proportion of the species found in any given locality are not reported from any other point, it will readily be understood why no attempt is made to work out any floral horizons in the Dakota group, when the reader observes that, while a portion of the species are reported from among a dozen localities, and a few specimens come from Minnesota and Nebraska, owing to the circumstances attending their collection and accumulation in Professor Lesquereux's hands, a large part, perhaps the greater number of them, have no more restricted habitat than "Ellsworth County, Kansas," or merely "Kansas." It is noted, however, that in one or two instances no change in the associations of the species was met in descending fifty or seventy-five feet in the series. The geological interest of the work would have been further increased if collections from the southwestern extension of the group had also been made and studied with the rest.

In the interpretation and elaboration of the author's last notes, some of which were fragmentary, and written after the lamented writer was unfit for work, as well as in interpreting and rearranging the extensive additions or modifications to the manuscript, Professor Knowlton, the editor, has shown great discretion, making no alterations or enlargements other than those necessary to the expression of the author's intended meaning, or for priority or consistency, such alterations being indicated by brief foot-notes. To him we are also indebted for a valuable tabulation of the geological and geographical distribution of the species, a compilation involving much time and consultation of the literature of the science.

It is unfortunate that those plates with washed drawings, made under Professor Lesquereux's personal supervision for the lithographer, should have, for financial reasons, been sacrificed, even though the photo-gravure work is of good quality. Much distinctness of the nervation is lost, as may be noted in a comparison with the last plates in the volume, prepared especially for the cheaper process. Although, as in too many of the paleontological publications of the United States Geological Survey, the date on the title page is earlier than the actual publication of the work, the date (1892) on the outside page is, in this instance, correct.

DAVID WHITE.

Cretaceous Fossil Plants from Minnesota. By LEO LESQUEREUX. Vol. III., Final Report on Geology and Natural History Survey of Minnesota. Feb. 15, 1893, pp. 1–22; pl. A. B.

The distinguished author of this short paper died in 1889, yet the evidences of his untiring energy are still coming to hand. This paper, bears internal evidence of having been prepared about the time of the completion of his *Flora of the Dakota Group*, which has likewise only just been published. It is prefaced by a short interesting account of the introduction and development of plant-life, illustrated by a wealth of examples and statistics.

Cretaceous fossil plants have been known from Minnesota for many years, in fact, several species were obtained by members of the Hayden survey, but this is the first complete systematic review of them. They come mostly from New Ulm, in Redwing Co., and Goodhue township in Goodhue Co. The amount of material examined was very scanty, there having been but fifty-five specimens, yet the richness of the flora is shown by the fact that there are twenty-eight species. Of this num-

ber, no less than eight are described as new to science. The new species belong to the genera Sequoia, Populus, Cissus, Alnites, Ficus, Diospyros, and Protophyllum. To these must be added four forms not specifically named, leaving sixteen species, having a distribution outside of the State of Minnesota. Of these sixteen species, fourteen are found in the Dakota group of Kansas and Nebraska, and six in the Cretaceous of Greenland, four species being common to the two localities. The species described as new, are more or less closely related to the forms from the Dakota group, or from the middle Cretaceous of Greenland, the whole serving to fix very definitely the horizon from which they came. The new, or especially interesting species are clearly depicted on the plates.

There are several obvious typographical errors as 'Kovne' for 'Kome,' 'nibrasciensis' for 'nebrascensis,' etc., which doubtless would not have occurred, had the author lived to read the proof himself.

F. H. KNOWLTON.

On the Organization of the Fossil Plants of the Coal-measures. By W. C. WILLIAMSON. Philosophical Transactions Royal Society, London: vol. 184 (1893) B. pp. 1–38; pl. 1–9.

This memoir, the nineteenth of this invaluable series, is devoted mainly to a consideration of the structure of *Lepidodendron Harcourtii.* This now classic plant was first named and described by Witham in 1833. It was also figured and described anew by Lindley and Hutton in their *Fossil Flora of Great Britain*, and was still later made the basis of an elaborate memoir by Adolph Brongniart. It was then referred by Brongniart to the cryptogams, but when he later discovered in allied forms, a secondary woody zone, developed exogenously outside of the central woody cylinder, he concluded that it must be a conifer. Williamson has long ago shown that the Lepidodendra frequently develop this secondary woody zone in mature stems, and that they are undoubted cryptogams. He was, however, unable to prove this for *L. Harcourtii*, for specimens well enough preserved to show internal structure, had not been before discovered. The present paper deals in an elaborate manner with all the authentic specimens, including the type of this species, and the author concludes that although none of the specimens were large enough to show the secondary thickening, this species is a true Lycopod, not unlike others of the genus Lepidodendron. Incidentally, the so-called genera Halonia and Ulodendron are treated of, the conclusion being that they are simply different forms of fruiting branches of Lepidodendroid and Sigillarian plants. This paper has a pronounced geological value, in that it affords a readily recognizable fossil, characteristic of a definite horizon.

F. H. KNOWLTON.

Analytical Abstracts of Current Literature.

Summary of Current Pre-Cambrian North American Literature.

Prefatory Note.—The summary of current pre-Cambrian literature beginning in this number, which will continue in following numbers, though probably not consecutively, is made upon somewhat different principles from those ordinarily used. The fundamental ideas of the plan are as follows: The summary proper and the comments are kept wholly separate, in this way preventing the confusion which frequently comes from a mingling of the two. In the summaries the original language of the author is used as far as practicable, although a single sentence may be taken from several sentences of the original. Where it is disadvantageous to use the original language other words are used. This often is necessary, because the language which is adapted to complete exposition is often not the best adapted to résumé. No quotations are made; for the ideas contained, whether in the original language or not, are wholly the ideas of the author, the whole is in fact really quoted. It might be thought that better results would be reached by indicating through quotations what words are taken from the original, but this method would necessitate an unpleasant and constant alternation from quoted to non-quoted phrases. As a result of experience with the two methods, the editor feels certain that he is able more accurately and fully, in a brief space, to represent the ideas of the original author by the method proposed, than by following the usual method.

The summaries are confined to articles or parts of articles pertaining to pre-Cambrian stratigraphy. Purely economic or petrological articles are not summarized unless they concern pre-Cambrian stratigraphy, in which case the substance of the conclusions are given, rather than a full account of the observations and the manner of reaching them. The abstracts have the defects of all summaries,—a certain amount of inaccuracy, because many modifying and qualifying facts can not be given, and because undue emphasis is placed upon the conclusions.

In many cases no comments are made. This does not imply that the editor agrees with the statements of the summaries. To criticize, qualify, or refute the statements of the authors in all cases of disagreement, would often

result in extending the space taken by the comments beyond that required for the summaries. However, when the points at issue are of general interest, or fundamental importance, it is advisable to make comments and enter into discussions, even if the space taken by such comments be greater than that given to the summary of the original articles. In such comments neither commendation nor censure will be made, but the aim will be to point out the conclusions announced which fail of complete establishment, and the generalizations which appear to go beyond what is warranted by the facts published. The purpose of indicating what appears to the editor as deficiencies of these kinds is neither to put himself dogmatically in opposition to the statements of the author reviewed, nor with the belief that his opinion has more weight, but to direct attention to the questions involved, and in cases of doubt to keep them open for farther study in the field and laboratory.

Mills [1] finds in the Sierra Nevada, unconformably below the Mesozoic, eruptive granites and sedimentary slates and quartzites. The latter in places rest and were probably deposited upon the granite, while in other places they are contemporaneous and imbedded within it. The quartzites are held to be silicified phases of the slates. These rocks in age may run from Archæan to the Paleozoic and some of them may be early Mesozoic.

Darton [2] finds Ordovician fossils in the crystalline slates and schists of the Piedmont plain of Virginia, these rocks having been previously regarded as Huronian.

Lesley [3] gives a summary sketch of the pre-Cambrian rocks of Pennsylvania, the facts being taken from the detailed state reports. The Highland Belt of New Jersey and Pennsylvania; the Reading and Durham Hills; areas in Chester, Bucks, Montgomery and Delaware counties; and an area on the Schuylkill river are placed in the Archean. All are regarded as sedimentary in origin, because of the presence of marble, apatite and iron ore. The newer gneiss of the Philadelphia belt, the Azoic formations of York, Chester and Lancaster counties, and the South Mountain rocks are not definitely referred to any system. The term Huronian must be used simply as a proper and private name for a series of rocks exposed along a part of the northern boundary of the United States. Should a similar series appear in some other region and be called Huronian on account of the resemblance, the name would have no value whatever; unless we should imagine that in a so-called Huronian age the whole surface of the planet was stuccoed with a certain formation; and

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[1] *Stratigraphy and Succession of the Rocks of the Sierra Nevada of California.* James E. Mills. Bull. Geol. Soc. of America, vol. 3, 1892, pp. 413–444.

[2] *Fossils in the "Archæan" rocks of Central Piedmont Virginia.* N. H. Darton. Am. Jour. Sci., 3rd series, vol. 44, 1892, pp. 50–52.

[3] *The Laurentian and Huronian Formations,* by J. P. Lesley, in A Summary Description of the Geology of Pennsylvania, Vol. 1. Rep. Penn. Geol. Sur., 1892, pp. 53–164.

received successive coats of other kinds of rock in after ages. The most dissimilar series of formations are known to be of the same age. What is happening to-day has happened in all ages. Nothing could be more unlike than the deposits now forming along the various ocean shores, and in different lakes and inland seas; yet they are all of one age. Even the deposits making in one and the same basin radically differ; as, for example, along the northern and southern sides of Lake Ontario; and along the eastern and western sides of Lake Champlain. It would therefore seem a useless task to seek for the Huronian rocks far from their native range.

Nason[1] fully describes the iron ores of the porphyry region of Missouri, and incidentally treats of the associated rocks. The porphyries usually show evidence of bedding, but this may be that of igneous flows. The Cambrian limestones and sandstones flank and rest unconformably upon the granites and porphyries. The iron ore of Iron Mountain and most of the other localities is in veins in the massive rock, probably of water infiltrated origin; or in a residuary mantle; or as concentrated detritus along the slopes or ravines of the porphyries. In the two latter cases the ore is derived from the veins. In some cases this concentration occurred before or during the deposition of the Cambrian sandstones and limestones, but in other cases is subsequent to the deposition of these rocks. At Pilot Knob the succession from the base upward is porphyry; conglomerate; a slaty ripple marked stratum in contact with the ore body; main ore body, nineteen to twenty-nine feet thick; highly ferruginous slate, one to three feet thick; heavy beds of conglomerate with an average thickness of one hundred feet. The pebbles of the conglomerate are mainly derived from the porphyries, but the regularly laminated slate and ore have a thin bedded structure, which is such as to lead to the conclusion that they are undoubtedly of sedimentary origin.

Bell[2] gives a general account of the Laurentian and Huronian systems, and a sketch of the geology of the country extending from Lake Huron northward to Lake Temiscaming, and from Lake Nipissing westward to the Spanish river. The Laurentian system is divided into an upper and a lower formation. The latter consists almost entirely of fundamental gneiss, while the upper Laurentian appears to consist of metamorphosed and sedimentary strata, to some extent at least.

The lower division of the Laurentian consists of red and gray gneiss, usually much bent or disturbed, and having generally a rudely foliated structure, and a solid or massive character. The feldspar is almost entirely ortho-

[1] *The Iron Ores of Missouri*, by Frank L. Nason. In Rep. Geol. Sur., Missouri, for 1891–2, Vol. 2, pp. 16–69. Jefferson City, 1892.

[2] *The Laurentian and Huronian Systems North of Lake Huron, accompanied by Geoolgical Map.* Dr. Robert Bell, Rep. of Bureau of Mines, Ontario, 1891, pp. 63–94. Toronto, 1892.

clase. The upper division of the Laurentian is more complex. It possesses more regularity in stratification and includes great banded masses of crystalline limestones, vitreous quartzites, mica-schist and hornblende-schist, massive pyroxene, and massive and foliated labradorite rocks. Considerable areas of granite and syenite occur in the formation. The Upper Laurentian of the Ottawa valley may be roughly estimated to be at from 50,000 to 100,000 feet in thickness.

While the older Laurentian rocks afford no proof of the permanent existence of the sea upon the earth, water appears to have been present, perhaps only as precipitations upon the surface, at every stage of its formation. But the deposits of limestone and tolerably pure silica in distinct bands in the Upper Laurentian afford strong support to the aqueous theory of its deposition.

With the beginning of the Huronian period great volcanic activity began, and there is evidence of the permanent abode of water on the surface of the earth. The general character of the Huronian rocks may be said to be pyroclastic, by this signifying that, although fragmental, they have nevertheless had an igneous origin.

The area mapped between the Huronian belt and the shore of Georgian bay appears to belong to the Upper Laurentian. The rocks are gneisses of the typical Laurentian varieties, finely stratified and regularly arranged in anticlinal and synclinal folds, the angles of dip usually not being far from forty-five degrees, but lesser and greater dips being found. Red and gray varieties are about in equal proportion, and they alternate with each other in thick and thin sheets. Mica-gneisses are predominant. No beds of crystalline limestone are found west of Iron Island in Lake Nipissing. Limestones are associated with the gneisses on some of the islands of the eastern part of this lake and at Lake Talon on the Mattawa. In the Parry Sound district are five distinct bands of Laurentian limestone. These rocks are classified with the Upper Laurentian rocks of the counties of Ottawa and Argenteuil.

The Laurentian rocks northwest of the Huronian belt are heavy contorted gneisses of the lower Laurentian. Associated with the gneisses are red granites which are classed with the Laurentian, but which may be really Huronian. These may have formed by softening the gneiss by heat, combined with re-crystallization, or they may be due to the alteration of the Huronian arkoses or graywackes, or they may be mainly eruptive. These granites are along the contact line between the Laurentian and Huronian. Along the line of contact between the granites and Huronian quartzites and schists, the rocks are much broken. It is not improbable that a fault exists at the line of junction between the Laurentian and Huronian rocks.

The great Huronian belt consists of a great variety of rocks, such as crystalline schists, quartzites, conglomerates, agglomerates, clay-slates, greenstones, dolomites, etc., the majority of which are pyroclastic. The rocks are

usually tilted at high angles. There are numerous instances where there is a gradual transition from the Huronion to the lower series. A few instances of local want of conformity between the two is no evidence that the two systems are not conformable on a grand scale. The few known instances where there appears to be a want of parallelism are more probably due to faulting. The pyroclastic rocks show the agency of water in their formation, and were largely derived from igneous matter, which had been more or less recently erupted. The newest rock of the Sudbury district is a volcanic breccia, which forms a continuous range of hills for a distance of thirty-six miles, with a breadth in the center of eight miles. Within the Huronian rocks are intrusive red granites.

Comments. Attention is called to the implication that the unconformity at the base of the Huronian, if it exist at all, is of a local character. The very idea of an unconformity pre-supposes that it can not be local in the narrow sense. A minor unconformity even marks a considerable time break, and when an earlier series has been profoundly metamorphosed and deeply denuded before the overlying series is deposited upon it, the break must be of regional extent, even if the contacts found are few and of small extent. It, however, does not follow that the break is universal nor even that it always extends throughout a geological basin. Space does not permit a discussion of the evidence for the existence of unconformable contacts at the base of the original Huronian in certain localities. It is enough to say that Irving, Pumpelly, Reusch, Barrois, and Tschernychew, all having seen one of the localities and the first two both, agree that the only interpretation of the phenomena at points near Garden river and near Thessalon is that of a great unconformity, not faulting as suggested by Bell, who does not appear to have ever visited these localities.

Barlow[1] states that the Huronian system is the oldest sedimentary strata of the north shore of Lake Huron, and that the Laurentian gneiss or Basement Complex is the original crust of the earth or floor on which the first sediments were laid down. This floor, as shown by the pebbles of the Huronian, was granite which had in many places a foliated or gneissic structure. In many places the subsequent folding and fracturing of the comparatively thin crust of the earth has caused large portions of the Huronian to sink below the plane of fusion, the result of which has been to produce irruptive contacts. At other places, as described by Pumpelly and Van Hise, the Basement Complex may have remained undisturbed so that the overlying detritals have not been intruded by the granitic mass beneath.

Hall and Sardeson[2] describe the Upper Cambrian rocks of Southeastern

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[1] *On the relations of the Laurentian and Huronian on the North Side of Lake Huron.* Alfred E. Barlow. Am. Jour. Sci., 3d series, vol. 44, 1892, pp. 236–239.

[2] *Paleozoic Formations of Southeastern Minnesota.* C. W. Hall and F. W. Sardeson. Bulletin Geol. Soc. of America, vol. 3, 1892, pp. 331–368.

Minnesota as resting unconformably upon a pre-Paleozoic floor. The base of the Potsdam is usually conglomeratic. At Minneopa a well 800 feet deep passed through a conglomerate for a distance of 225 feet, the pebbles of which are vitreous quartzite like those occurring in Cortland, Watonwan and Cottonwood counties. A conglomerate containing granitic debris is found on Snake river about two miles above Mora, and three miles distant from the Ann River knobs of hornblende-biotite-granite, the clastic appearing to be derived from the granite. At Taylors' Falls a conglomerate made up of pebbles of diabase rests upon the diabase of the St. Croix river. These underlying formations are Archean and Algonkian rocks.

Grant [1] states that the Animikie rests unconformably upon the Saganaga granite; that the Ogishki conglomerate is intruded by the Saganaga granite, and therefore that the Ogishki conglomerate is earlier than and separated by a great structural break from the Saganaga granite. As the Keewatin has the same relations to the Saganaga granite as the Ogishki conglomerate, the same thing is true of the Animikie and Keewatin. The Ogishki conglomerate is younger than the most of the Keewatin, but is considered as a part of it.

Comments:—The most characteristic and abundant fragments in the Ogishki conglomerate are granite. The rock occurs in pieces running from those of minute size to great bowlders. It is manifest that this material was derived from a pre-existing granite. These bowlders are in all respects like much of the Saganaga granite, and the probability is very strong that this is their source. Grant is probably correct as to the intrusion of the conglomerate by a granite, but this granite may have also intruded the main Saganaga mass. The too frequent mistake has apparently been made of concluding that in the Saganaga area there is granite of but one age, when frequently in the great massives of the Northwest, granites of several ages occur, the latest ones cutting all the previous ones, and often the far newer clastics. It further follows that the implication that the Animikie is unconformably upon the Ogishki conglomerate needs the support of additional evidence. That this conglomerate is possibly more nearly related to the Animikie than to the Keewatin is shown by the presence of abundant jasper fragments, presumably derived from the Keewatin. The article appears to be another illustration of the facts being right, the author in his interpretation, however, overlooking a part of the facts which are to be accounted for in making a true generalization.

Winchell [2] gives a review of the literature on the Norian of the Northwest. Here are included the gabbros, placed as the basement member of the

[1] *The Stratigraphic Position of the Ogishke Conglomerate of Northeastern Minnesota.* U. S. Grant. Am. Geologist, vol. 10, 1892, pp. 4–10.

[2] *The Norian of the Northwest*, by N. H. Winchell. In Bull. 8, Geol. and Nat. Hist. Sur., Minn. 1893, pp. iii–xxii.

Keweenawan by Irving, and the Bohemian Mountains of Keweenaw Point. It is suggested that the anorthosites of Lawson are but facies of the gabbro, and that the two belong together in the Norian.

Comments : — This paper correlates with the so-called Norian of the East the gabbros and similar rocks of the Lake Superior region, which have heretofore been considered as constituting a part of the Keweenawan. Such lithological correlations are believed to retard, rather than advance geological progress, as they rest wholly upon unverified assumptions. The local name Keweenawan ought to be retained for the gabbros and allied rocks, or else some new local name ought to be devised for it. This latter is done by Lawson as appears from the paper next summarized.

Lawson[1] gives a petrographical and structural account of the anorthosites of the Northwest shore of Lake Superior. The anorthosite is wholly massive, completely granitic in structure, and is composed almost wholly of basic feldspar, varying in composition from labradorite to anorthite. The rock occurs near Encampment Island, in the vicinity of Split Rock point, at Beaver Bay and vicinity, at Baptism river, on the slopes of Saw Teeth mountain, and at Carlton Peak. In nearly all of these localities the rock is found in rounded dome shaped masses below the other eruptives of the coast. It is cut by these different eruptives, and in the lava flows are found very numerous blocks and bowlders of anorthosite, which were caught in at the time of their extrusion. These facts show that the anorthosite is of pre-Keweenian age, and since the anorthosite is a plutonic rock, it must have suffered profound erosion prior to the extravasation of the Keweenian eruptives. Norwood, Irving and Winchell have described the blocks of anorthosite in the lavas at some of the points. Winchell regarded the anorthosite at Split Rock as older than the eruptives containing masses of them, and Irving reached the same conclusion in reference to the anorthosite at Carlton Peak. However, none of them differentiated the anorthosite mass from the general aggregation of volcanic flows, constituting the Keweenian series of the Minnesota coast. The surface of the pre-Keweenian anorthosite is domed and hummocky like that of the other Archean terrains of Canada, and it is thought to have been only modified by Pleistocene erosion. The interval between the anorthosite and the Keweenian is probably the same as the pre-Paleozoic interval which effected the reduction of the Archean to the great hummocky plain, to which it was reduced before the Animikie was deposited upon it. As the Keweenian rests directly upon the anorthosite, the Animikie is absent for the middle third of the Minnesota coast. Irving places the thickness of the Keweenian of the area at 20,000 feet, stating that it may reach 22,000 or 24,000 feet. The maximum thickness of the

[1] *Anorthosites of the Minnesota Shore of Lake Superior*, by A. C. Lawson. In Bulletin 8, Geol. and Nat. Hist. Sur., Minn., 1893, pp. 1–23.

Keweenian is not more than one-tenth of this thickness. Irving's subdivision of the Keweenian into groups, and his estimate of the thickness of various portions of the series are of little value; a statement which it is as painful to make as it is necessary in the interests of sound geology. The anorthosite is provisionally correlated with the Norian of the Province of Quebec, but as this correlation is merely a hypothesis, the name Carltonian is suggested for this formation.

Comments:—The main structural conclusion of Lawson, that the anorthosite of the Northwest shore of Lake Superior is older than and was deeply eroded before the deposition of the upper Keweenawan lava flows, seems clearly established, and this is a conclusion of great importance. However the general inferences which are drawn from this relation call for more evidence.

At the outset it is to be noted that the term Paleozoic is extended to include the Keweenian and Animikie series, a usage not followed by many and involving a great proposition which demands evidence. The question is, however, too large to discuss here.

The Keweenaw series of Northeastern Minnesota is of great extent and thickness. Irving, in his latest paper on the pre-Cambrian divided the Keweenawan into two divisions, a lower basal gabbro, and an upper series, consisting of thinly-bedded basic and acid rocks.[1] The anorthosite is but a facies of gabbro, in which the pyroxenic constituent is reduced to a minimum. The most probable explanation of the relations made out by Lawson, as it appears to me, is that the anorthosite exposed on the coast belongs with this great basal gabbro, and this is the position which is apparently favored by Professor Winchell,[2] although he regards the whole gabbro mass as pre-Keweenawan. This latter is a matter of definition, and is contrary to the general usage of the term in the past, both divisions having been generally regarded as making up the Keweenawan. The length of the period represented by the Keweenawan was so great, that after the outflow or intrusion of the basal gabbro there may have been along the Minnesota coast a period of erosion, thus cutting deep into the gabbro, anorthosite and associated rocks. Later in Keweenawan time this eroded surface was covered by the flows of the upper division. Indeed this unconformity between the basal gabbro of the Keweenawan and the upper, more thinly-bedded members of the series was noted by Irving[3] both for the Bad River area of Wisconsin and for Minnesota, and is

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[1] *The Classification of Early Cambrian and pre-Cambrian formations*, by R. D. Irving. In 10th Annual Rep. U. S. G. S., pp. 418–420.

[2] *The Norian of the Northwest*, by N. H. Winchell. In Bull. Nat. Hist. and Geol. Sur., Minn., pp. 28, 19.

[3] *Copper Bearing Rocks of Lake Superior*, by R. D. Irving. In Third Annual Rep. of Director U. S. G. S., pp. 134, 136, 137. Also Mon. 5, U. S. G. S., pp. 155, 156, 158, 159.

reinforced in the latter case by his map of Northwestern Minnesota, which suggests that the upper division of the Keweenawan overlaps the lower unconconformably.

In the first of these areas the thin-bedded flows are described as being poured out against the gabbro mass, which, it is said, must have stood to a great height, until finally the flows accumulated sufficiently to cap the upper surface of the gabbro. So strongly was Irving impressed by these facts, that he states that he was inclined at first to place the gabbros of the Bad River district with the Huronian, and to regard them as the equivalents of the great flows of the Animikie series of Thunder Bay, but, finding the Animikie slates unconformably under the gabbros, he preferred to put them as the earliest division of the Keweenawan, clearly recognizing that there was a very considerable unconformity between these coarse, massive rocks and the later thinly-bedded ones. This reference was made because of the close lithological relationship of the gabbro and the Keweenawan diabases, and because in eruptive series such breaks were regarded as less significant.

It thus appears that Irving fully appreciated an unconformity, probably at the horizon of Lawson's unconformity, but he did not recognize that the break which has so extensive an occurrence also exists along the Minnesota coast. If the explanation suggested as to the relations on the Minnesota coast be true, Irving's statements, used in reference to the Bad River area, can be applied almost exactly to this one, in which case the difference between Irving and Lawson is that of nomenclature. Lawson restricts the term Keweenawan to the upper part of the series, whereas Irving and other writers regarded the Keweenawan as including both divisions. It also follows, if the anorthosite is Keweenawan, that Lawson's conclusion that the Animikie is absent below the Keweenawan in Northeastern Minnesota, is without foundation, for the base of the Keweenawan thus defined is not here exposed. Further, the Animikie is certainly unconformably below the great basal gabbro of Minnesota. It further follows that the correlation of the anorthosites of Lake Superior and those of the Province of Quebec has no value. But, wholly apart from the stratigraphy of Northeastern Minnesota, I must confess to a complete lack of confidence in the correlation of eruptive rocks so far removed as these.

To the statement that Irving's subdivision of the Keweenawan into groups and his estimate of the thicknesses of various portions of the series are of little value, I feel that I must take exception. The painstaking character of all of Irving's work is well-known. He spent many years of study upon the series in Michigan and Wisconsin. His study, and that of his assistants, Messrs. Chauvenet, Cambell and McKinley, on the northwest coast of Lake Superior was of a detailed character. It would seem scarcely possible that Dr. Lawson's study of the stratigraphy in a single trip, in which he made no attempt to re-measure the sections (so far, at least, as can be ascertained from his paper) could have been detailed enough to warrant this sweeping state-

ment. On one point Irving seems not to have fully drawn the conclusion which legitimately followed from his observations. This, however, does not invalidate the observations in any way, nor lessen the strength of the many important conclusions which were reached. The only particularized notice by Dr. Lawson of these supposed errors is in reference to the thickness of the Keweenawan. The statement that Irving overestimated this thickness tenfold certainly needs additional justification. The thicknesses given are maxima for the particular region. Irving was perfectly well aware that the Keweenaw series varies greatly in thickness from place to place, being largely of volcanic origin. He also knew that it varies from its maximum thickness to entire disappearance at a not very remote distance from the Lake Superior basin. That a volcanic series is not of great thickness in one particular area of a region is no evidence that it is not so in other parts. If the anorthosite division of the Keweenawan constituted a mountainous mass for the central part of the Minnesota coast, and the upper Keweenawan beds were deposited against them, as before suggested, these later beds may have a very great thickness remote from the anorthosites, or at the inaccessible base of the past mountain range, and this would be quite in accordance with a moderate thickness near the tops of the anorthosite domes.

Lawson[1] describes the laccolitic sills of the northwest coast of Lake Superior. The trap sills are mainly diabases, but they occasionally pass into gabbros. It is held that there are no contemporaneous volcanic rocks in the Animikie group, and that the trap sheets are intrusive in their origin, rather than subsequent volcanic flows, for the following reasons: They are simple geological units, one not overlapping another; they have a uniform thickness over areas more than 100 square miles in extent; where inclined, the dip is due to faulting and tilting; they have no pyroclastic rocks associated with them; they are not glassy nor amygdaloidal; they show no flow structure, or other distinct properties of effusive rocks; their contacts with the slates are sharp; they never repose upon a surface which has been exposed to weathering or erosion; they are analogous to the great dikes of the region in all their relations; they may be observed in direct continuity with dikes; they pass from one horizon to another; they have a columnar structure extending throughout their thickness; apophyses pass from the main sheets into cracks of the slate above and below; they locally alter the slates above and below them.

The Animikie strata have been dislocated by a great system of faults, the orographic blocks having been frequently tilted. The non-recognition of this prevalent tilted structure has led to very excessive estimates of the thickness of the series by Irving and Ingalls. In the vicinity of Black Sturgeon River

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[1] *The Laccolitic Sills of the Northwest Coast of Lake Superior*, by A. C. Lawson. In Bull. 8, Geol. and Nat. Hist. Sur., Minn., pp. 24–48.

and on the Isles of Nipigon Bay are numerous places where Keweenian strata are capped by thick sheets of trap, identical with those which cap the Animikie, but, though these sheets cannot be traced in absolute continuity in the interval, there are many outlying patches which fill the gap. The same trap sheets are found in several instances to pass from the Animikie to the Keweenian, and there are the same evidences of intrusion of independent trap sheets in the Keweenian that are in the Animikie. These rocks are, therefore, of post-Keweenian age, and, to discriminate them from the Keweenian and Animikie, they are designated the Logan sills.

Comments : — The fact that all the trap sheets of the Animikie studied by Lawson are intrusive is no evidence that in other areas, not studied by him, there may not be contemporaneous volcanics. The traps in the Triassic of Connecticut and New Jersey are an illustration of this point, a part of them being extrusive and a part intrusive. Also in the Penokee series, the equivalent to the Animikie series, while for the main part of the area there are no contemporaneous volcanics, in the eastern end of the series there suddenly appears a great thickness of contemporaneous volcanic fragmentals, and such may occur in the Animikie in the areas not yet studied.

The inclination of the Animikie series was fully recognized by Irving and Ingall, and this it was which led them to make their estimates of the thickness. The statement, that the strata have been dislocated by a great system of faults, may be true, but in the paper it is not supported by any evidence; and, until detailed evidence is presented, the conclusion of Irving and Ingall as to the thickness seems more probably true than the hypothesis of numerous faults.

Because the sills are later than the Animikie and Keweenawan strata which they have intruded, is no sufficient evidence that they are post-Keweenawan. The thickness of the Keweenaw series is so great that it is quite reasonable to expect that correlative with the later extrusions were intrusions between the older Keweenawan strata. To explain all the facts cited on the northwest coast it is only necessary to suppose that the upper part of the Keweenawan has been removed by erosion, and that the sills now composing the upper layers in these places were overlain at one time by higher members, which have subsequently been removed by erosion. This is not a violent supposititition, for it is well known that erosion and volcanic extrusion alternated many times in single areas during Keweenawan time.

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(*Further acknowledgments of pamphlets already received will be made in the next number.*)

THE

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ON THE TYPICAL LAURENTIAN AREA OF CANADA.

THE name Laurentian was given by Logan in 1854 to the great series of rocks forming the Laurentides or Laurentian Mountains, a district of mountainous country rising to the north of the River and Gulf of St. Lawrence, and extending in an unbroken stretch along the shore of the latter from Quebec to Labrador, a distance of nine hundred miles. This district, with its continuation to the west as far as Lake Huron, being situated in the Province of Quebec and the adjacent portion of the Province of Ontario, and forming part of the main Protaxis of the continent, is the "Original Laurentian Area" of Logan. The Laurentian rocks are now known to extend far beyond the limits of this area to the west and north, constituting, as they do, by far the greater part of the Protaxis, and underlying (with subordinate patches of Huronian) an area of somewhat over two million square miles.[1] The area above referred to is, however, the one which was first studied and described; it is the "Typical Laurentian area," and to it the observations in the present paper will be as far as possible confined.

A general exploration of the area in question, and a more detailed study of a small part of it—the Grenville District—situated in the counties of Argenteuil and Terrebonne in the Prov-

[1] Accepting the distribution of the Laurentian in the far north, given by Dr. G. M Dawson, as correct, the area is 2,001,250 square miles. This does not include the outlying and separated areas occurring in Newfoundland, New York State and Michigan.

ince of Quebec, was carried out by Logan and his assistants in the early years of the Canadian Geological Survey. An excellent résumé of the results of these studies is given in the "Geology of Canada," published in 1863, which contains not only a good description of the general petrographical character and arrangement of the rocks which make up the area, but is accompanied by an atlas containing two maps illustrating this description, one showing the general distribution of the Laurentian in the eastern part of the Dominion, and the other its stratigraphical relations in the smaller area above referred to.

As a result of these studies, Logan announced his belief that the Laurentian System consisted of two great unconformable series of sedimentary rocks, to which he gave the names Upper and Lower Laurentian. The latter he considered to be divisible into a lower and an upper portion, which sub-divisions he regarded as probably conformable to one another. In the course of time these several series came to be known as the Anorthosite or Norian Series, the Grenville Series and the Fundamental or Ottawa Gneiss. Logan's views may then be represented as follows:

Anorthosite or Norian Series,	Upper Laurentian.	
Grenville Series,	Upper portion	Lower Laurentian.
Fundamental or Ottawa Gneiss,	Lower portion	

Subsequently, in the southeastern corner of the Province of Ontario, in the district lying to the north of the eastern end of Lake Ontario, another series of rocks was discovered—the so-called Hastings Series. Logan supposed this to come in above the Grenville Series, while Vennor, who subsequently examined the district, believed it to be equivalent to the lower part of the Grenville Series already mentioned.

When these investigations were carried out, the microscope had not as yet been seriously employed in petrographical work. The precise composition of many of the rocks making up the several series was not recognized, the effects produced by great dynamic action were not duly considered, and the foliation possessed in a high degree by some and to a certain extent by almost all these

rocks was considered, in all cases, to be a more or less obliterated survival of original bedding. The detailed mapping in the field, accompanied by microscopical work in the laboratory, by which alone conclusive results can be obtained in working out the structure of complicated areas of crystalline schists, was not carried out, in fact in many districts the construction of detailed maps was at that time practically impossible. It is not surprising therefore that, although excellent in the main, some of the results arrived at have since proved to be erroneous.

It is proposed, in the present paper, to place before the readers of this Journal in as brief a manner as possible, a general account of the several series of rocks occurring in this area, and to point out what, in the opinion of the present writer, seems to have been satisfactorily established concerning the statigraphical position and mutual relations of these ancient rocks and what still remains to be determined by further study, and in conclusion to give a short sketch of the evolution of this portion of the continent.

The Fundamental Gneiss.—Exposed over very wide stretches of country in Canada, and making up in all probability by far the larger part of the Archean Protaxis, is the "Fundamental Gneiss," sometimes called, from its great development about the upper waters of the Ottawa River, the "Ottawa Gneiss." It is composed essentially of orthoclase gneiss, usually reddish or greyish in color. Of this there are a number of varieties, differing from one another in size of grain, relative proportion of constituent minerals and in the distinctness of the foliation or banding. It is sometimes rich in quartz, while at other times this mineral is present in but very small amount. It is usually poor in mica and bisilicates. Dark bands of amphibolite are not uncommon, while basic hornblende or pyroxene gneisses occur in some places. Other schistose rocks are rarely found. Over great areas it is often nearly uniform in character and possesses a foliation which can only be recognized when exposures of considerable size are examined. On this account it is often referred to as a granitoid gneiss, a designation, however, which by no

means accurately describes it as a whole. At a locality cited by Sir William Logan, as one where it is typically developed, namely, Trembling Mountain in the above mentioned Grenville Area, it consists of a fine grained reddish orthoclase gneiss, with distinct but not very decided foliation, containing here and there bands of orthoclase gneiss of somewhat different character; as well as bands or layers of a dark amphibolite.

How much of this Fundamental Gneiss really consists of eruptive material is not known. The indistinct foliation, in many cases at any rate, is not a survival of original bedding, but is clearly due to movements in a plastic mass. It is often possible to recognize the existence of an indistinctly foliated gneiss intruded into more distictly foliated gneiss. The gneiss, in some cases, shows excellently well-marked cataclastic structure, while in other cases this is not distinct. The evidence accumulated goes to show that the Fundamental Gneiss consists of a complicated series of rocks of unknown origin, but comprising a considerable amount of material of intrusive character.

The Grenville Series.—In certain parts of the Laurentian area, and notably in the Grenville district before mentioned, the Laurentian has a decidedly different petrographical development. Orthoclase gneiss is still the predominating rock, but it presents a much greater variety in mineralogical composition, and is much more frequently well foliated, often occurring in well defined bands or layers like the strata of later formations.

Amphibolites are abundant, also hornblende schists, heavy beds of quartzite and numerous thick bands of crystalline limestone or marble, all these rocks being interbanded or interstratified with one another. In the vicinity of the limestones the variety in petrographical character is especially noticeable; garnets often occur abundantly in the gneiss, the quartzite and the hornblende schist, as well as in the limestone itself, beds of pure garnet rock being found in places. Pyroxene, wollastonite and other minerals are also abundant, while the presence of graphite disseminated through the limestones and their associated rocks, often in such abundance as to give rise to deposits of economic

value, is of especial significance. This mineral which is not found in the Fundamental Gneiss, occurs usually in little disseminated scales but occasionally in veins. The limestones are thoroughly crystalline, generally somewhat coarse in grain and often nearly pure. They usually, however, contain grains of serpentine, pyroxene, mica, graphite or other minerals, of which over fifty species have been noted. They are often interstratified in thin bands with the gneiss, in places are very impure, and may be traced for great distances along the strike, being apparently as continuous as any other element of the series. This development of the Laurentian is known as the Grenville Series, and has been considered by all observers to be above and to rest upon the Fundamental Gneiss. In it are found all the mineral deposits of economic value—apatite, iron ore, asbestos, etc., which occur in the Laurentian. The rocks of this series, though generally highly inclined, over some large areas lie nearly horizontal or are inclined at very low angles, but even in such cases they show evidence of having been subjected to great pressure, resulting in some cases in the horizontal disruption of certain of the beds.

The areas occupied by the Grenville series although of very considerable extent, being known to aggregate many thousand square miles, are probably small as compared with those underlain by the Fundamental Gneiss. The relative distribution of the two series has not been ascertained except in a general way in the more easily-accessible parts of the great Archean Protaxis. The Grenville series is known to occupy a large part of its southern margin between the city of Quebec and the Georgian Bay, while the discovery of crystalline limestone in the gneiss elsewhere at several widely separated points, as for instance on the Hamilton River in Labrador, in the southern part of Baffin Land and on the Melville Peninsula, makes it probable that other considerable areas will, with the progress of geological exploration, be found in the far north. Over the greater part of the Protaxis, however, the more monotonous development of the Fundamental Gneiss seems to prevail.

The question of the origin and mutual relations of the Fundamental Gneiss and the Grenville series is one about which, though much has been written but little is known. Three views may be taken on the matter—

(1) The Fundamental Gneiss may be supposed to contain what remains of a primitive crust, penetrated by great masses of igneous rock erupted through it—the whole having been subjected to repeated dynamic action.[1] The Grenville Series may be an upward continuation or development of the Fundamental Gneiss under altered conditions, marking in the history of the world the transition from those conditions under which a primitive crust formed to those in which sedimentation under the present normal conditions took place. It would seem that if the earth originally had a crust on which the first sediments were deposited when the temperature became sufficiently low to permit water to condense, that the said water, at a very high temperature and under what are to us now inconceivable conditions but little removed from fusion, might give rise to sediments not altogether similar to those formed by the ordinary processes of erosion at the present time. Also that, under the unique conditions which must have prevailed at that early time, in the formation of a crust solidification, precipitation and sedimentation might go on to a certain extent concomitantly, and thus no well-defined break could be detected, or would in fact exist, between a primitive crust formed by solidification from a fused magma and the earliest aqueous sediments or deposits. The Fundamental Gneiss and the Grenville Series might thus, as Logan supposed, form one practically continuous series and represent parts of the original crust, with the first crystalline or clastic sediments deposited on it, the whole penetrated by eruptive rocks and folded up and altered by repeated dynamic action at subsequent periods.

The general petrographical similarity of the two series, taken in connection with the more varied nature of the Grenville Series,

[1] See also, The Geological History of the North Atlantic, by Sir William Dawson, Presidential Address, B. A. A. S., 1886.

its frequent stratified character, and the presence in it of limestones and graphite indicating an approach to modern conditions and the advent of life, together with the difficulty of clearly separating the two series from one another and defining their respective limits, lends support to this view.

(2) A second view is that the Grenville Series is distinct from the Fundamental Gneiss reposing on it unconformably and of much more recent age; that it consists of a highly altered series of clastic origin—the Fundamental Greiss having possibly some such origin as that mentioned under the last heading, or representing a much older series of still more highly altered sediments. This is supported by the fact that some observers have thought they could in places trace out a line of contact between the two. But in these cases it always becomes a matter of serious doubt whether what has been considered to represent the Fundamental Gneiss is not really a mass of intrusive rock, in which, by pressure or motion, a somewhat gneissic structure has been induced. If the Fundamental Gneiss, moreover, was ever an ordinary sediment, it must have undergone a metamorphosis so profound that no trace of clastic origin remains, unless the generally indistinct foliation or banding of some portions of it be considered as such. It must also be noted in this connection that, although the rocks of the Grenville series are more frequently possessed of a decided foliation and are often banded, bands of different composition alternating with one another as in ordinary sedimentary deposits, and although in this series crystalline limestones and quartzites occur, we have as yet no absolutely conclusive proof that even they are of sedimentary origin. The series is thoroughly crystalline, most of its members at least show the effect of great dynamic action, and so far as the present writer is aware, no undoubted conglomerate or finer grained rock showing distinct clastic structure has ever been found. In view of this fact,—although the series is, in all probability, made up in part at least and perhaps wholly of sedimentary material,—the proposal to separate it from the rest of the Laurentian and class it as Algonkian or Huronian seems at least premature.

(3) A third view which has been advanced is that the Fundamental Gneiss is nothing more than a great mass of eruptive granite or granitic rock which has eaten upward, and in places penetrated the Grenville series, or perhaps absorbed it, while the Grenville series itself represents a series of highly altered sediments of Laurentian, Huronian or subsequent age. The enormous extent and world-wide distribution of the Fundamental Gneiss forming as it does wherever the base of the geological column is exposed to view, the foundation or floor on which all subsequent rocks are seen to rest, is opposed to this view of its origin, as is also its persistent gneissic or banded character, although, as above mentioned, much eruptive material is undoubtedly to be found in it.

Which of these views is correct can be ascertained only as very careful and detailed mapping, accompanied by accurate petrographical study, is proceeded with. In the present state of our knowledge additional argument and discussion will not help us toward the goal, while hasty work and generalization serves but to retard the progress of our knowledge.

The Anorthosite Series.—Associated with both the series of rocks just described there are, as has been mentioned, great eruptive masses of granite, some of which have been folded in with the gneisses, while others evidently erupted at a much later date, show no trace of dynamic action.

In addition to these, basic eruptive rocks belonging to the gabbro family occur in certain districts, sometimes in the form of comparatively insignificant masses, but elsewhere underlying great tracts of country. One on the upper waters of the Saguenay has an area of no less than 5,800 square miles. These usually consist of a variety of gabbro in which the magnesia-iron constituents are present in very small amount, being in many cases entirely wanting, so that the rock consists practically of pure plagioclase feldspar. These rocks were called *anorthosites* by Hunt, in the early reports of the Canadian Geological Survey, on account of the great preponderance in them of "Anorthose,' a general name given many years ago by Delesse to the triclinic

feldspars, as distinguished from "Orthose," or orthoclase feldspar, and thus equivalent to the term plagioclase now in general use, but having no connection with anorthite, a variety of plagioclase which is seldom present. After a careful study of these rocks, both in the field and the laboratory, it is believed that this name should be retained for this well-marked member of the gabbro family, which, though not a common rock elsewhere, has an enormous distribution in the Laurentian of Canada.

If an olivine gabbro be regarded as the central member, so to speak, of the gabbro family, the replacement of the monoclinic by rhombic pyroxene will give rise to an olivine norite. A gradual diminution in the amount of plagioclase will give rise to a peridotite or gabbro pyroxenite, a diminution in the amount of pyroxene to a troktolite or plagioclase-olivine rock, while a diminution in the amount of olivine and pyroxene will give rise to an anorthosite, which variety forms the greater part of the intrusive masses in question. The gradual passage of one variety into another can be distinctly traced in many localities in the anorthosite masses. These anorthosites are in some places massive, but very frequently show a distinct foliation, often very perfect. In some places they occur interbanded with the gneiss and crystalline limestone, while elsewhere they cut directly across the strike of these rocks. The interbanded anorthosite, together with the gneiss and limestone associated with it, was supposed by Logan to form a distinct sedimentary series, to which the name "Upper Laurentian," or "Norian," was given, because the discovery that elsewhere the anorthosite runs across the strike of the gneiss was supposed to indicate that this series covered up and unconformably overlay the Grenville series, the igneous and intrusive character of the anorthosite not being recognized on account of its frequently foliated structure. It is now known that these anorthosites do not constitute an independent formation, but are igneous rocks which occur, cutting both the Grenville series and the Fundamental gneiss. They have, however, in many cases been intruded before the cessation of the great dynamic movements to which the Laurentian was

subjected in pre-Cambrian times, and thus frequently taking a line of least resistance and having been intruded between the bands or strata of the Grenville series, have had a foliation induced in them parallel to that of the gneiss, while in other cases where they are more or less massive, they cut across the the strike of the latter.

In many cases the anorthosites which exhibit a perfect foliation may be traced step by step into the massive variety, the gradual development of a foliated structure in the rock being accompanied by a progressive granulation of the constituents, most beautifully seen under the microscope. The change, however, differs from any hitherto described in that it is purely mechanical. There are no lines of shearing with accompanying chemical changes, but a breaking up of the constituents throughout the whole mass, though in some places this has progressed much further than in others, unaccompanied by any alteration of augite or hypersthene to hornblende, or of plagioclase to saussurite, these minerals, though prone to such alteration under pressure remaining quite unaltered, suffering merely a granulation with the arrangement of the granulated material in parallel strings. This process can be observed in all its stages, and there is reason to believe that it has been brought about by pressure acting on the rocks when they were deeply buried and very hot.[1] The anorthosite areas, of which there are about a dozen of great extent with many of smaller size, are distributed along the south and southeastern edge of the main Archean Protaxis from Labrador to Lake Champlain, occupying in this way a position similar to that of volcanoes along the edge of our present continents. Curiously enough precisely similar occurrences of this anorthosite have been found in connection with similar gneissic rocks, supposed to be of Archean age, in Russia, Norway and Egypt. These anorthosite rocks being intrusive, may be left out of consideration in endeavoring to work out the succession of the Archean in this great area.

[1] See FRANK D. ADAMS—"*Ueber das Norian oder Ober-Laurentian von Canada,*" *Neues Jahrbuch für Mineralogie, etc., Beilageband VIII., 1893.*

The whole Laurentian system, including the anorthosites, is in many places cut by numerous dykes of large size, which can often be traced for great distances. These are of several kinds, the principal series consisting of a beautiful fresh diabase often holding quartz in considerable amount in micro-pegmatitic intergrowths with plagioclase. Other sets of dykes and eruptive masses consisting of augite and mica syenites, quartz-porphyries and other rocks are also known to occur but have not as yet been carefully studied.

The Hastings Series.—The stratigraphical relations of the Hastings series have not as yet been satisfactorily determined. The rocks constituting the series differ widely in petrographical character from those of the Fundamental Gneiss and the Grenville series, both of which are supposed to occur in its immediate neighborhood. The series consists largely of calc-schists, mica-schists, dolomites, slates and conglomerates, thus containing much material of undoubtedly clastic origin. It has moreover a very local development, being confined, so far as at present known, to one small corner of the area, as has been mentioned. It was by Logan supposed to come in above the Grenville series, while Vennor who subsequently examined the district, believed it to be equivalent to the lower part of this series. That we have in the Hastings series a comparatively unaltered part of the Grenville series, made up largely of rocks whose origin is easily recognized, would be a most important fact if established, and would, of course, afford a key to the whole question of the origin of the latter. This is a conclusion, however, which cannot be accepted until supported by very clear and decisive evidence, especially as the stratigraphy of the Hastings district is very complicated, the several series represented in it being much folded and penetrated by great masses of eruptive rocks. The whole district has also been subject to great dynamic action, some of the pebbles in the conglomerates of the Hastings series being distorted in a most remarkable manner. This series may prove to be merely an outlying area of Huronian rocks folded in with the Laurentian, and until the district has been studied in

detail its stratigraphical position must remain a matter of conjecture.

Leaving the Hastings series out of consideration therefore, we have in this Original and Typical Laurentian area two developments of the Laurentian, generally considered as constituting two series, namely the

Grenville or Upper series,
Fundamental, Ottawa, or Lower Gneiss.

The Evolution of the Area.—In endeavoring to outline the main events in the evolution of this area it will be necessary to extend the limits of our observation somewhat and seek for evidence bearing on the question in other parts of the Protaxis, where we meet with developments of Huronian and various earlier Paleozoic strata not found in the typical area itself.

From the highly contorted condition of the Laurentian rocks of this area as well as from the abundant evidences of dynamic action which they present both in the field and under the microscope, it is evident that they have been subjected to great orographic forces, which in very early times threw them up into mountain ranges, probably of great height. Some of the associated eruptive rocks were intruded before these movements began, or while they were in progress and have accordingly been influenced by them, while others, having been intruded later, have not been affected.

How high these mountains rose cannot of course be determined. Bell states that some of the mountains on the Labrador coast now rise to a height of from 5,000 to 6,000 feet, while Lieber has estimated that on the coast of Northern Labrador they rise to a height of from 6,000 to 10,000 feet. Along the southern part of the Protaxis, where the country is much lower, notwithstanding the enormous subaerial denudation and glaciation which the area has repeatedly undergone, there are many points still rising from 2,500 to 3,500 feet above sea level, while Logan estimated that the average elevation is from 1,500 to 1,600 feet. In the Adirondacks, which are but an outlying portion of this area, there are elevations of over 5,400 feet.

The high elevations attained by these rocks in portions of the Protaxis in the north may, of course, be due to differential elevation, but immediately along the southern edge of the area there can have been but little differential change of level as compared with the flat-lying Potsdam strata which border it and lie but little above the present sea level. Further evidence of the original height or continued uprising of the area is afforded by the fact that all the material of which the North American continent was built up (with the possible exception of some of the limestones) was derived originally from the Archean Protaxis of the continent, a considerable proportion of this at least coming from the main Protaxis of which this typical Laurentian area forms a part. We must conclude therefore that in early Cambrian or pre-Cambrian times, in portions of the Protaxis at least, the Laurentian mountains rose several hundred and possibly in places several thousand feet above the sea level.

The intrusion of the granites and anorthosites as well as the folding of the whole system of rocks took place before Upper Cambrian times. The whole series was moreover without doubt at that time in the "metamorphic" condition in which we now find it, for along the margin of the area the Potsdam sandstone rests in flat undisturbed beds on the deeply eroded remnants of these old mountains, its basal beds often consisting of a conglomerate with pebbles of the underlying gneissic rocks. These Cambrian strata cover up the gneisses, granites and anorthosites alike and are evidently of much more recent age, being separated from the Laurentian by the long interval occupied in the upheaval and erosion of the Laurentian area.

How long before Upper Cambrian times this folding and erosion took place cannot be determined from a study of this area, but further west along the edge of the Protaxis in the Lake Superior district we find that the Keweenawan, Nipigon and Animikie Series also repose in flat undisturbed beds on the eroded remnants of a series of crystalline rocks which have the petrographical character of the Fundamental Gneiss. This

makes it at least very probable that in this eastern area also the erosion took place in pre-Cambrian times.

It is a very remarkable fact that the roche moutonné character possessed by these eroded Laurentian rocks and which is usually attributed to the glaciation which they underwent in Pleistocene times, was really impressed upon them in the first instance in these pre-Cambrian times, for all along the edge of the nucleus from Lake Superior to the Saguenay, the Paleozoic strata, often in little patches, can be seen to overlie and cover up a mammillated and roche moutonné surface showing no traces of decay and similar to that exposed over the uncovered part of the area. The conclusion therefore seems inevitable that not only were these Laurentian rocks sharply folded and subjected to enormous erosion, but that they had given to them in pre-Cambrian times their peculiar hummocky contours so suggestive of ice action.[1] The pre-Paleozoic surface of the Fundamental Gneiss of Scotland, as Sir Archibald Geikie has shown, also presents the same hummocky character.[2] On this surface the Upper Huronian, Cambrian, and later Paleozoic rocks were deposited.

To what extent the seas of Cambrian, Silurian and Devonian times passed over this area cannot be determined with certainty. A great series of rocks referred to by Dr. G. M. Dawson as probably of Lower Cambrian age and analogous in character to the Keweenawan and Animikie series occur overlying the Laurentian in many parts of the Protaxis, not only along its margin, but as outliers at many places in the interior. It occurs extensively developed about the Arctic Ocean and about Hudson's Bay, and a large area of rocks referred to the same age also occur near the height of land about Lake Mistassini. "Throughout the whole of the vast northern part of the continent this characteristic Cambrian formation, composed largely of volcanic rocks, apparently occupies the same unconformable position with

[1] A. C. Lawson.—"Notes on the Pre-Palaeozoic surface of the Archean Terranes of Canada." Bulletin of the Geological Society of America. Vol. 1, 1890.

[2] "A Fragment of Primeval Europe." Nature, August 26, 1888.

regard to the underlying Laurentian and Huronian systems. Its present remnants serve to indicate the position of some of the earliest geological basins, which from the attitude of the rocks appear to have undergone comparatively little disturbance. Its extent entitles it to be recognized as one of the most important geological features of North America."[1] It would, therefore, seem that in Cambrian times a not inconsiderable part of the Archean Nucleus was under water. Outliers of Cambro-Silurian age are also found at several points lying well within the margin of the Nucleus, as for instance in the Ottawa River about Pembroke at a distance of fifty miles, and at Lake St. John at the head of the Saguenay River at a distance of one hundred and thirty miles from its present limit. There is reason to believe that a similar outlier exists in the interior of the northern part of the Peninsula of Labrador, so that the Lower Paleozoic sea must also have covered considerable areas in the eastern half of the Protaxis, where now nothing but Laurentian is to be seen. In that portion of the Protaxis lying to the west of Hudson's Bay strata of Cambro-Silurian and Devonian age extend up from the basin of Hudson's Bay on the east and from the great plains on the west far over the Laurentian Plateau and probably, according to Dr. Dawson, originally inosculated. Strata of Upper Silurian and Devonian age are not known to exist in the eastern half of the Protaxis, of which the typical Laurentian area forms part, with the exception of a small outlier of Niagara age on Lake Temiscamangue at the head waters of the Ottawa—neither do any other deposits of later age occur with the exception of the Glacial Drift. What evidence there is, therefore, would rather indicate that the area, during late Paleozoic, Mesozoic and earlier Tertiary times, was out of water. If so, it must have undergone during this great lapse of ages a process of deep seated decay and denudation, culminating in the extensive glaciation to which it was subjected in Pleistocene times.

During this latter period the whole area was exposed to

[1] G. M. Dawson.—"Notes to accompany a geological map of the northern portion of the Dominion of Canada." Report of the Geological Survey of Canada, 1886. p. 9, R.

ice action, with the exception of the highest part of the Nucleus —the mountains of the Labrador coast—which, except toward the base, are still "softened, eroded and deeply decayed."[1] This extensive denudation served to remove all but mere remnants of any Paleozoic strata originally deposited on the Archean of this area, while the deep decay of the Archean rocks themselves would account for the immense numbers of gneiss bowlders in the drift, which in all probability are but smoothed cores of "bowlders of decomposition." That an immense amount of material was removed from the surface of the area during the glacial age is shown by the immense quantities of Archean material which occurs scattered over the surface of the Nucleus itself, as well as in the drift to the south. The glaciation, with the depression and uplift which succeeded it, was the last episode in the evolution of this "original" Laurentian area and one which impressed upon it its present surface characters and type of landscape.

It is now an immense uneven plateau, comparatively slightly accentuated except along the Labrador coast. The surface is covered with glaciated hills and bosses of rock with rounded, mammilated, flowing contours interspersed with drift covered flats and studded with thousands upon thousands of lakes great and small. A country which in the far north is often bleak and desolate, but to the south, where it is covered with luxuriant forest, is often of great beauty, especially when clothed with the brilliant foliage of autnmn. Even now, however, it is passing into a further stage of its history, the smooth or polished glaciated surfaces are becoming roughened by decay, the softer gneissic and limestone strata are again commencing to crumble into soil, and a new epoch has been inaugurated in which the marks of the ice age are being gradually effaced.

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[1] ROBERT BELL.—"Observations on the Geology etc., of the Labador Coast, Hudson's Strait and Bay." Report of the Geological Survey of Canada. 1882–3–4, p. 14, DD.

MELILITE-NEPHELINE-BASALT AND NEPHELINE-BASANITE FROM SOUTHERN TEXAS.

These basaltic rocks were collected by Professor Dumble and Mr. Taff, in Uvalde County, southern Texas. On the geological map of the United States, compiled by C. H. Hitchcock, 1886, there are two of the localities marked near the boundary of the Cretaceous and earlier Tertiary formation, between 99° and 100° longitude, and on the 29th degree of latitude. According to the statement of Professor Dumble, one part of the rocks appears in dikes in the upper portion of the lower Cretaceous formation, while the other forms hills and buttes. Upon microscopical examination it is evident that the specimens collected belong to two different groups of rocks. The microscope shows that those occurring in dikes consist of typical melilite-bearing nepheline-basalt, while those making up hills and buttes are nepheline-basanites tending toward phonolites in composition.

The melilite-nepheline-basalts have a typical basaltic appearance. In a dense black groundmass, the only phenocrysts seen by the naked eye are numerous olivines. Under the microscope there appear in addition to the olivine the following minerals: augite, nepheline, melilite, magnetite and perovskite. As to the proportion of nepheline and melilite, it can be said, that in nearly all the specimens examined, the two minerals are found in about the same amount. For this reason these rocks can be placed under the head of nepheline-basalt as well as under that of melilite-basalt, or they may be called melilite-nepheline-basalt. Only one of the specimens is entirely free from melilite. Feldspar is wholly wanting. All of the specimens are in a very fresh condition, and even the melilite shows only slight indications of decomposition. The specimen free from melilite corre-

sponds in structure and composition with the other specimens, except for the absence of melilite and perovskite, and so they may be described together.

All the rocks are porphyritic, since they bear large phenocrysts of olivine. Under the microscope the olivine is colorless and transparent, and only shows indications of serpentinization along the edges and fissures. It contains roundcd inclusions of glass, abundant in some sections, besides octahedrons of magnetite, and others that are transparent with a brownish violet color. Whether the latter are a mineral of the spinel-group or belong to perovskite, with which they accord in color, could not be decided.

Augite occurs in only one generation; phenocrysts of augite are wanting. In the rather coarse-grained groundmass, it becomes the most abundant constituent. The mineral shows a grayish-brown color, common to basaltic augite, sometimes with a tint of violet. It generally forms well-shaped crystals, rarely irregular grains, and bears inclusions of magnetite and glass.

Melilite occurs in the groundmass in large and well-shaped crystals, its dimensions never becoming as small as those of many of the augite crystals. They may be designated as microporphyritical phenocrysts. Cross sections parallel to (001) reach a diameter of 0.5 mm. The shape of the melilite is the common one, tabular parallel to (001). The diameter of the tables generally exceeds their thickness from four to six times. Sections parallel to the prism-zone, therefore, are lath-shaped and the vertical axis lies perpendicular to their length; the axis of greatest elasticity coincides with the vertical axis. Between crossed nicols these sections show the particular blue interference colors characteristic of melilite and zoisite. Sections perpendicular to the prism-zone are eight-sided by reason of the planes (110) and (100), but frequently the outlines are rounded. In some of the sections examined the melilite incloses minute opaque grains arranged zonally, which present very sharply the prismatic outlines of their host. Besides the two prismatic faces above mentioned, there is also a ditetragonal prism, the angle of which upon the adjoining faces of (110) and (100) was found

to be nearly equal, 20°–22°. According to this measurement the prism must have approximately the position of (940); the angle of the latter upon (110) is 21° 2′, the angle upon (100) = 23° 58′. A particular phenomenon in the growth of the melilite is the fact that the base does not generally present an even plane, but shows a conical depression. The shape of the lath-shaped sections then resembles the profile of a biconcave lens. Sections parallel to the base are isotropic between crossed nicols and show, when they are not too thin, an indistinct dark cross in convergent light. The cleavage parallel to (001), the cross-fibration of the lath-shaped sections and the occurrence of the spear-shaped and peg-shaped inclusions arranged parallel to the *c* axis (the so-called *Pflockstruktur*) are very distinct. Inclusions of pyroxene, magnetite and glass are common; as already mentioned, these inclusions are generally arranged in zones. In sections parallel to (001) they fill the central parts of their host, and often make up two or three concentric zones. These sections closely resemble leucite because of their rounded shape, the arrangement of the inclusions and the lack of double refraction. Melilite becomes nearly colorless and transparent, but in comparing it with the white, colorless nepheline, it shows a feeble yellow tint. Decomposition has taken place to only a small extent; it begins along the cross-fibration, and greenish-yellow alteration-products result, the fibres of which are perpendicular to the length of the lath-shaped sections.

Nepheline is always fresh, colorless and transparent; it rarely exhibits a regular shape, but generally forms an aggregate of irregular grains, cementing the other components; it is evidently the latest formed mineral in the rock.

There is abundant magnetite besides perovskite, the common associate of melilite, which occurs in small octahedrons and irregular grains. The perovskite becomes transparent with a brownish-violet color, and shows in some sections a feeble, abnormal double refraction. There appears to be no isotropic base in the normal rock, but if any is present, it must be in a very small amount. There are coarser grained spots in the rock,

which are rich in a partly chloritized base, and in which nepheline occurs in well-shaped crystals.

The second group of rocks, as already mentioned, falls under the head of nepheline-basanite poor in olivine. And since the specimens bear sanidine phenocrysts beside plagioclase, it forms a transition to phonolite. The rock-specimens have a more andesitic than basaltic appearance. Numerous phenocrysts of hornblende and augite are imbedded in the dense bluish-gray groundmass. The next most abundant mineral is nepheline in the form of phenocrysts, in part well-shaped crystals, in part rounded, the largest of which are 0.5 cm. in diameter. The nepheline differs from the feldspar in having a grayish color and greasy lustre. Phenocryst of feldspar and crystals of olivine are scarce. Beside these components, the rocks contain apatite, some titanite and iron ores. Under the microscope olivine is seen to be scarce. It is fresh and shows the normal properties. It contains minute octahedrons of picotite and in some sections abundant inclusions of a liquid with moving bubbles.

The amphibole mineral is a typical basaltic hornblende. It becomes transparent with a dark reddish-brown color and exhibits a strong pleochroism according to the following scheme:

$\mathfrak{a}$, brownish yellow, $\mathfrak{b}$ and $\mathfrak{c}$ dark reddish brown. Absorption, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The angle of extinction was examined in sections cut approximately parallel to the clinopinacoid (010) and was determined to be very small. This fact and the dark reddish-brown color are in all probability due to a high amount of Fe_2O_3. The dependence of the angle of extinction upon the amount of Fe_2O_3 in minerals of the amphibole group has been recently established by Schneider and Belowsky. The basaltic hornblende shows the well-known dark borders produced by reabsorption by the magma in an early stage of consolidation. In many cases nothing of the original mineral is preserved; the whole hornblende is replaced by a fine grained aggregate of pyroxene and magnetite, presenting clearly the outlines of the absorbed mineral.

The group of pyroxenic minerals is represented by two mono-

clinic augites. One of them exhibits a violet-gray color in thin section and belongs to the basaltic augites; the other one becomes transparent with a dark green color. Both form numerous phenocrysts, but the first occurs somewhat more frequently. They occur as single crystals and are also grown together in a zonal manner, the green one always forming the center, the gray one the outer parts of the crystals. Hence the gray augite is the younger. The pyroxene in the groundmass shows the same color and properties. The pleochroism of the two minerals is as follows:

	Gray augite.	Green augite.
$\mathfrak{a}$	Brownish-yellow	Light yellowish-green
$\mathfrak{b}$	Violet-gray	Dark gray-green.
$\mathfrak{c}$	Violet-gray	Dark green.

The angle of extinction, c: $\mathfrak{c}$, is large and, as may be seen in the zonal crystals, it is somewhat larger in the gray pyroxene than in the green. The extinction in sections cut approximately parallel to (010) has been observed to be about 47 degrees (gray augite) and 41 degrees (green augite). The two pyroxenes show in addition to the cleavage parallel to (110) another but less distinct one parallel to (010). Inclusions of magnetite, apatite and glass are common.

Phenocrysts of feldspar are scarce. In part they show the polysynthetic twinning lamination of plagioclase; in part the latter is wanting and one of the latter feldspars, which was isolated and examined for specific gravity and optical properties, was found to be sanidine. Phenocrysts of nepheline are more frequent than those of feldspar. The mineral appears partly in the form of short-prismatic crystals, partly in rounded grains. It presents distinct cleavage, parallel to (10$\bar{1}$0) and to (0001), and the usually observed optical properties. Isolated grains are decomposed by hydrochloric acid with the separation of gelatinous silica; the resulting solution when evaporated gives numerous cubes of NaCl. Inclusions are scarce; there are fluid cavities with moving bubbles, generally arranged in rows, besides some pyroxene crystals.

Apatite forms short and stout crystals always filled with in-

clusions of liquids. The opaque ore grains, judging by their ready solubility, belong to magnetite. The groundmass of these rocks consists essentially of pyroxene in well-shaped prisms, lath-shaped feldspar, without twinning lamination or in single twins according to the Carlsbad law and nepheline. The feldspar of the groundmass in all probability is mostly sanidine. Nepheline is abundant and occurs in well-shaped crystals. Small patches of a colorless base occur between the crystalline components.

The structure of the rocks is hypocrystalline-porphyritic on account of the occurrence of an isotropic base and the repetition of the crystallization of pyroxene, nepheline and feldspar. Although the specimens by their whole habit and structure belong under the head of nepheline-basanite poor in olivine, the presence of sanidine as phenocrysts causes them to form a transition to the group of phonolites. Unfortunately, analyses of these rocks have not yet been made.

A microscopical examination of the basaltic rock from Pilot Knob, near Austin, Travis County, was made for the purpose of comparison with the rocks from southern Texas just described. The rock was found to be a nepheline-basalt porphyritic with numerous phenocrysts of olivine. The fine grained groundmass consists essentially of augite-crystals cemented by non-individualized nepheline in very small amount.

A. Osann.

SOME DYNAMIC PHENOMENA SHOWN BY THE BARABOO QUARTZITE RANGES OF CENTRAL WISCONSIN.

THE quartzite ranges of Baraboo extend east and west for about thirty miles, one lying north, and the other, the main range, lying south of the City of Baraboo. The geology of this district is admirably given by the late Professor Irving.[1] Not only is the general geology clearly described, but remarkably accurate descriptions are given of the character of the quartzite, and the phenomena shown by it, considering the fact that the report was written nearly twenty years since. The unconformity existing between the quartzite and the Cambrian was later more fully described.[2] The induration of the Baraboo quartzite has been explained as due to the enlargement of the original quartz grains; and to the deposition of independent interstitial quartz.[3] The present note is based upon recent observations on the East Bluff at Devil's Lake and on the exposures at the Upper Narrows of the Baraboo River.

The section across the ranges, as given by Irving, is shown by Fig. 1. The two ranges together, as thus represented, are less than the north half of a great anticline, the south side of the south range being near its crown. This structure involves a very great thickness of quartzite, and was offered with reservation by Professor Irving. He says: "The hypothesis is not altogether satisfactory. The entire disappearance of the other side of the great arch, as well as the peculiar ways in which the

[1] The Baraboo Quartzite Ranges, by R. D. Irving. In Vol. II, Geol. of Wis., pp. 504–519.

[2] The Classification of the Early Cambrian and pre-Cambrian Formations, R. D. Irving. In 7th Annual Rep., U. S. G. S., pp. 403–408.

[3] Enlargement of Quartz Fragments and Genesis of Quartzites, by R. D. Irving and C. R. Van Hise. In Bull. 8, U. S. G. S., pp. 33, 34.

ranges come together at their extremities are difficult to explain by it. It may be said in this connection that the dip observations toward the west are not so satisfactory or numerous as they might be." The question naturally arises whether or not the great width of the ranges in the central part of the area may not be partly explained by monoclinal faulting, and thus reduce the supposed thickness of the beds.

The layers of quartzite are ordinarily very heavy, but the changing character of the original sediment is such as to make it easy to follow the layers. Some beds were composed of fine

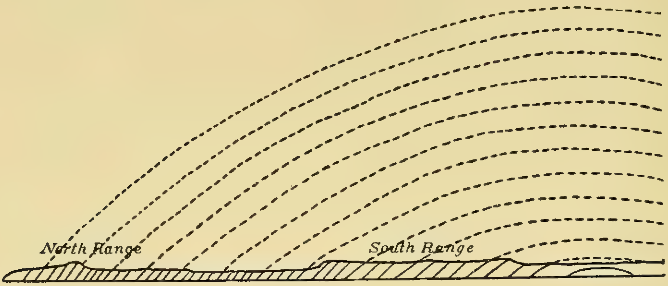


FIG. 1.—Ideal Sketch, showing structure and amount of erosion of the Barboo Ranges. After Irving.
Scale natural, 12,000 feet to the inch.

grains of quartz, mingled with clayey material, others of coarse grains with little clayey material, and others of pebbles so large as to pass into an unmistakable conglomerate. The pebbles of the conglomerate are mainly white quartz and red jasper. It is thus easy to discriminate the bedding of the series from the heavy jointing which occurs, cutting the bedding in various directions, and from a secondary cleavage and foliation which occurs in certain localities.

From the general work of many geologists on dynamic action in folding, it is to be expected that the amount of movement necessary for accommodation between beds, and consequently the dynamic metamorphism resulting from shearing, would be less near the crown of the anticline than on the leg of

the fold. That is, dynamic metamorphism ought not to be so extensive in the south range as in the north range. The facts described by Irving,[4] and those noted by me, fully agree with this anticipation. The central parts of the heavy, little inclined beds of the south range are largely indurated by simple enlargement. The pressure has not been sufficient to obliterate the cores, but has apparently granulated the exterior of some of the larger fragments, as in hand specimens the exteriors of the large blue quartz grains are white. Very generally the grains show slight wavy extinction. A few of them are distinctly cracked. The crevices thus formed and those in the interstices have been filled in large part by infiltrated silica, but their positions are plainly indicated by difference in extinction, by bubbles, by iron oxide, or by secondary mica which has taken advantage of the minute crevices.

However, as described by Irving, between the heavy beds of quartzites are often layers, cut by a diagonal cleavage which dies out in passing into the thick beds. The layers showing cleavage sometimes pass into those showing the beginning of foliation, the rock then nearing a schist. In the centers of the schist zones, the schistosity approaches parallelism with the bedding, and in passing outward curves from this direction until it crosses the bedding at an angle, at the same time becoming less marked and grading into ordinary cleavage, which dies out in the quartzite. Upon the opposite side the transition is of the same character, but the curve is in the opposite direction.

Irving apparently regarded these shear zones as originally beds of a different character from the adjacent quartzite, and his conclusion is fully borne out by the thin sections. The microscope shows that the grains of quartz are of small size, and separated to a greater or a less extent by interstitial clayey material. Because of this partial separation of the grains of quartz, they have not been granulated to the extent that one would expect from the schistosity of the rock, most of the original

[4] The Baraboo Quartzite Ranges, by R. D. Irving. In Vol. II, Geol. of Wis., pp. 510, 516.

cores being plainly visible. They, however, often show wavy extinction and even cracks, but not to a greater degree than the grains in the massive quartzite; for in the latter the full stress of the pressure has been borne by the grains in full touch, not separated by a plastic matrix, as are the grains of quartz in the argillaceous layers. In the matrix of the schist are numerous small flakes of muscovite, arranged with their longer axes in a common direction, much finely crystalline quartz, and a good deal of iron oxide.

It is concluded that the clayey character of the beds, and, consequently, the greater ease of movement within them, has located the slipping-planes and shear-zones, necessary in order to accommodate the beds to their new positions. On the south range, near Devil's Lake, these shear-zones are generally not more than six or eight inches wide. They may be well seen just back of the Cliff House, and on the Northwestern Railway, about one-half mile south of this house. All of these shear-zones are parallel with the bedding, and illustrate the possibility, so far as I know first mentioned by H. L. Smyth, that a crystalline schist, with schistosity parallel to bedding, may be produced by shearing along the bedding-planes.

On the railroad track, near the locality where these shear-zones may be seen, is also an almost vertical shear-zone, two to four feet wide. It therefore cuts almost directly across the beds of quartzite, which here incline to the south about twelve or thirteen degrees. Throughout this band, the quartzite is broken into angular trapezoidal fragments, the longer directions of which are vertical, and which may be picked out with the hammer. In certain parts of the zone well-defined gruss or friction clay, produced by the grinding of the fragments against one another, has been produced. This is clearly a plane of faulting. How much the throw of this fault is it is not easy to say, as the heavy beds of quartzite are so similar that it is impossible to certainly identify them. At this place there is, however, a change in the character of the quartzite, layers of light color being overlain by other beds, which are more heavily stained with iron oxide. This

same succession is seen on both sides of the fault, and if beds of like character correspond, the amount of the throw is twenty to thirty feet, and the south side has dropped relative to the north side. In other words, the faulting is in the right direction to reduce the theoretical thickness of the sediments as given by Irving. The district has not been closely examined for other faults, but the existence of one fault, even of a minor character, suggests that a careful study of the whole area with reference to faulting should be made, in order to determine what deductions may possibly be made from Irving's estimate of the probable thickness of the quartzite.

At the upper narrows of the Baraboo, near Ablemans, we are on the north leg of the anticline. The dip is throughout from seventy to ninety to the north, and in some places the layers are slightly overturned. The slipping along the bedding has here been much greater. While in this area there are heavy beds of quartzite which have not suffered great interior movement, other beds have been sheared throughout, being transformed macroscopically into a quartz-schist, but the foliation is strongly developed. In other places, as described by Irving,[1] where the rock is a purer quartzite, for a distance of 200 feet or more across the strike, the rocks have been shattered through and through, and re-cemented by vein quartz.

For the most part the rock is merely fractured, the quartz fragments roughly fitting one another, but there are all gradations from this phase to a belt about ten feet wide of true friction conglomerate, the fragments having been ground against one another until they have become well-rounded (a Reibungs breccia). Between the boulders of this zone is a matrix, composed mainly of smaller quartzite fragments. The whole has been re-cemented, so that now the mass is completely vitreous. This belt of friction conglomerate at first might not be discriminated from the Potsdam conglomerate, immediately adjacent, but a closer study shows how radically different they are. In

[1] The Baraboo Quartzite Ranges, by R. D. Irving. In Vol. II., Geol. of Wis., p. 516.

one the cementing material is vein-quartz; in the other the sandstone has been feebly cemented by quartz enlargement.

A movement later than the one which produced the cemented fractured rocks and breccia has broken broad zones of the massive beds of quartzite into lozenge-shaped blocks, the longer axes of which are parallel to the bedding and movement. These later-formed blocks have not been re-cemented by secondary quartz, and the cracks are taken advantage of in quarrying, the fragments being easily picked apart. Thus the rock has been affected by at least two dynamic movements, separated by a considerable interval of time.

The shear-zones, often several feet in width, particularly affect the more finely-laminated layers, which are lean in quartz, while the relief in the more massive layers has resulted in complex fracturing. In the first phase of production of the schist, the irregular fractures pass into rather regular fractures, cutting the beds nearly at right angles. As the action becomes more intense in the more argillaceous beds, the angle of fracture, or cleavage, as it may now fairly be called, becomes more acute, and in the most intense phase this cleaved rock passes into a well-developed schist, the foilation of which is parallel to the bedding. The phenomena of shearing are here therefore very similar to those at Devil's Lake, except that the process has gone farther.

When studied in thin section, the massive beds of quartzite show more decided effects of dynamic action than at Devil's Lake. However, the major portions of the grains of quartz have distinct cores which are often beautifully enlarged. In some cases nearly every grain has thus grown, perfectly indurating the rock. But, also, nearly every grain of quartz has a wavy extinction, and many of them have been fractured, as mentioned of a few of the quartz grains of the quartzites of the south range. In one case the pressure has been so great as to produce rather numerous roughly parallel lines of fracture. It is thus seen that the dynamic effects are not confined to the schist zones, but are also prominent within the heavy beds of quartzite. This was to

be expected; for while the major part of the accommodation necessary to bend the rock mass as a whole took place along the shear zones, the accommodation required to bend each of the rigid heavy beds of quartzite must have taken place within each layer. To the consequent intense pressure and the rubbing of the grains over one another, are wholly attributed their wavy extinction and fractures.

In the schists of the shear zones, as at the south range, the thin sections show that the original quartz grains were small; interstitial material was present, and mica has developed more largely than in the quartzite. However, in the most crystalline phases, the fragmental cores of the quartz grains and their frequent enlargements are plainly seen. Thus the shearing has not been sufficient to produce a completely crystalline schist, although this would not be macroscopically discovered, unless it were suspected because the rock is not thinly foliated.

As the dip of the quartzite is so steep at this locality, it is difficult to say how far the shifting of the beds over one another lessens the apparent thickness. The shear zones as well as the friction conglomerates appear to be parallel to the bedding. If they are exactly so, this shearing action would necessitate an estimate of the original thickness greater than now shown, since the shear zones probably have less width at the present time than the beds from which they were originally produced.

Cutting the bedding are heavy joints inclined to the north at an angle of 20° to 30°. If slipping had occurred along these in the right direction, this might cause a small thickness of beds to have a great apparent thickness. However, the schists above described weather out on the face of the cliffs, and are therefore marked by recessions in the walls. If slipping parallel to the jointing had occurred since the schists were formed, these depressions ought not to match on opposite sides of the joints; but, on the contrary, they continue unbroken from foot to top, and probably the joints were formed simultaneously with or later

than the belts of schist. Consequently, at the upper narrows of the Baraboo no evidence was found of faulting which could reduce the estimated thickness of the quartzite as given by Irving.

As Irving clearly saw, bearing strongly in favor of the theory of a great fold, is the increasing steeper dip of the layers in passing north. The phenomena of movement and metamorphism corresponding so exactly to those required by a simple fold, the question may be asked if these are not evidence of some weight in favor of the general correctness of Irving's conclusion as to the structure. Had monoclinal faulting extensively occurred, it would not have been necessary to have had so great a readjustment of the beds as has been shown to occur by the schists, cleavage, and the exceedingly intricate macro-fracturing and micro-fracturing of the rock beds and their constituent particles.

In addition to the phenomena described by Irving, in summary, the Baraboo quartzite ranges show results of dynamic metamorphism as follows: A fine example of the Reibungs Breccia may be seen. A fault zone of limited throw exists. All phases are exhibited, between a massive quartzite, showing macroscopically little evidence of interior movement through a rock exhibiting in turn fracture and cleavage, to a rock which macroscopically is apparently a crystalline schist. The foliation of the schists is parallel to the original stratification, being consequent upon the movements of the beds over one another, readjustments occurring mainly in the softer layers. In thin sections the schists still give clear evidence of their fragmental origin, but also show the mechanical effects of interior movement. These same effects are apparent within the heavy beds of quartzite, some readjustment of the particles to their new positions being here also necessary. There is no evidence that the semi-crystalline character of the schist and quartzite are due to high heat. Nowhere are the particles fused. So far as they are destroyed it is by fracture, and the rock is again healed by cementation.

The rock, in its most altered condition being a semi-crystalline schist, and in other parts showing less change, can be connected with its original state. Had the folding been more intense, it is reasonable to suppose that the entire rock would have been transformed into a completely crystalline quartz-schist, showing no evidence of clastic origin, and possibly the foliation throughout would have corresponded to the original bedding.

C. R. VAN HISE.

THE CHEMICAL RELATION OF IRON AND MANGANESE IN SEDIMENTARY ROCKS.

Iron and manganese are frequent constituents of sedimentary rocks, in some places occurring finely disseminated through sandstones and shales, or forming a part of limestones, in other places forming the mass of the deposit in which they occur. They are both derived primarily from similar, and often from the same sources, and are in many respects alike in their chemical behavior in nature. For these reasons it is to be expected that they would frequently, if not generally, be deposited in intimate association. Such is found to be the case, and iron and manganese are often closely associated in the same deposits. Very often, however, iron and manganese deposits occur close together, but distinctly separated, while sometimes extensive deposits of iron, and less commonly of manganese, occur with little or almost no association with each other.

It is the object of the present paper to discuss the agencies which are instrumental in causing these substances to be deposited sometimes together and at other times separately. The subject is of interest as showing how slight differences in the chemical behavior of their salts may cause the almost complete separation of metals once intimately associated.

THE CONNECTION OF IRON AND MANGANESE IN NATURE.

A few words concerning the relation of manganese to iron in nature will perhaps make the following discussion clearer. One of the most common modes of occurrence of manganese is with iron, though extensive deposits containing manganese more or less free from iron often occur. When associated with iron, manganese occurs with it in various ways. Sometimes the two are intimately mixed, so that they have the appearance of a homoge-

neous mass, resembling iron ore when iron is in the preponderance and manganese ore when manganese predominates. In such cases there appears to be no tendency to combine in one fixed proportion, though, as iron is a much more abundant substance than manganese, the mixture most commonly contains an excess of iron, and exists in the form of a manganiferous iron ore. The manganese, when not intimately mixed with the iron, may occur in it in pockets or as scattered nodules and concretions. Such occurrences as those described are frequent in the Lake Superior iron region, the Appalachian Valley of the eastern states, in Nova Scotia, Arkansas, Colorado, New Mexico and innumerable other places. In Virginia very common occurrences are alternating layers of iron and manganese ore. The iron in such cases is generally in the larger quantities and the more continuous deposits; while the manganese is often represented by thin lenticular layers or by bands of nodules.

From such cases, where iron predominates, there are all gradations in admixture, up to the rarer cases where manganese predominates. Frequently a given geologic horizon is characterized by both iron and manganese, though in one case it may contain only iron, in another only manganese, and in still another iron and manganese mixed in various proportions. A remarkable case of this is seen in the iron and manganese horizons immediately above, or a short distance above, the Paleozoic quartzite, on the east side of the Appalachian Valley, especially in the Valley of Virginia.[1] Here deposits of iron ore, of manganese ore, and of both ores mixed, are found at various points along the same geologic horizons. Similar alternations also occur in the Lower Silurian novaculites of the Ouachita Mountains of Arkansas,[2] in Cebolla Valley, in Gunnison county, Colorado,[3] and in

[1] The exact age of the iron and manganese deposits here referred to is, in some cases, a little uncertain. Some may be Cambrian, others Silurian, but the exact determination of the age of the horizon is not a part of the present discussion. The matter has been discussed by the writer in Geological Survey of Arkansas, 1890, Vol. I., pp. 376–379.

[2] See Geological Survey of Arkansas, 1890, Vol. I., pp. 320–325.

[3] See Geological Survey of Arkansas, 1890, Vol. I., pp. 456–457.

many other places. In many cases certain horizons are characterized over large areas by iron alone, and but little manganese, as is well seen in the Clinton formation and in the Tertiary iron-ore horizons of Arkansas and Texas; while, on the other hand, some areas of certain horizons contain considerable quantities of manganese and very little iron, as is seen in parts of the Marine limestone in New Brunswick and Nova Scotia, and also in parts of the metamorphosed Cretaceous shales of California.

THE SOURCE OF IRON AND MANGANESE IN SEDIMENTARY ROCKS.

The iron and manganese contained in sedimentary strata may be considered as derived primarily from the decay of pre-existing rocks. Some of the later sedimentary rocks may have derived a part or all of their iron from older sedimentary rocks, which, in turn, had derived their iron and manganese from still older rocks. In this way the iron and manganese in a given geologic horizon may have formed a part of various older horizons before they reached their present resting place, but, in every case, their primary source can be traced back to the original materials from which sedimentary rocks were first formed. In certain cases the sea water has supplied a certain amount of iron and manganese to sedimentary rocks, but in such cases the sea water acts only as a carrier of these materials from the land areas or from submarine sources to the strata then forming.

THE TRANSPORTATION OF IRON AND MANGANESE IN NATURE.

The process that goes on in this interchange of iron and manganese from older to younger rocks is as follows:

(1) The conversion, by surface agencies, of the minerals containing iron and manganese into forms that can be taken into solution by surface waters.

(2) The solution of the iron and manganese in surface waters, acidulated with organic and sometimes inorganic acids, and their transportation in this form from the areas of older rocks to areas over which younger rocks are being deposited.

(3) Finally, the precipitation in one or more of several ways of the iron and manganese contained in solution.

The iron and manganese thus chemically precipitated may be deposited either with mechanical sediments, such as sand, clay etc., or without them. If the deposition of mechanical sediments is largely in excess of the precipitation of iron and manganese, the final products will be beds of ferruginous shale, sandstone, etc., common in many geologic horizons. If the precipitation of iron and manganese is in excess of the deposition of mechanical sediments, the resulting products are deposits of more or less pure iron and manganese ore. Between these two extremes there are all gradations in the admixture of the iron and manganese with mechanical sediments.

Frequently the iron and manganese which were originally finely disseminated through shale, sandstone, etc., are subsequently concentrated into bodies of comparatively pure ore, and very commonly this concentration takes place by a process of re-solution of the iron and manganese and re-deposition by replacement with limestone, or, more rarely, with some other material. The limestone or other material which thus acts as a precipitant is often in the same series of strata from which the iron and manganese were removed, and thus these two substances, which were once in a finely disseminated condition, may be converted into deposits of comparatively pure ore and yet remain in the same general series of strata in which they were originally deposited. A remarkable case of this is seen in the iron deposits of the Penokee series in Michigan and Wisconsin,[1] to be mentioned again on page 370. It has also been suggested by H. D. Rogers[2] that certain siderite deposits in the Coal Measures were formed by the conversion of finely disseminated sesquioxide of iron into carbonate of iron by organic matter, and the subsequent segregation of the carbonate as now found in layers and nodules.

The surface waters that carry the iron and manganese to the strata being deposited at a given time are sometimes derived

[1] R. D. Irving and C. R. Van Hise, U. S. Geol. Survey, Tenth Ann. Report, 1888–1889, Vol. I, pp. 409–422.

[2] Geol. Survey of Penn., Vol. II, 1858, p. 739.

from areas in which iron predominates, sometimes from areas in which iron and manganese are both abundant, and sometimes, though rarely, on account of the scarcity of such regions, from areas in which manganese largely predominates over iron. If iron and manganese were always precipitated from these waters in similar chemical forms and under the same conditions, it would be expected that the strata deriving their iron and manganese from surface waters would contain those substances in the same relative proportions as they had existed in the rocks from which they were derived, and that they would be in an intimately mixed condition. Such is doubtless often the case, or at least approximately so; but it is also often the case that iron and manganese occur in separate deposits, yet in close proximity to each other and often alternating along the same horizon. Besides this, the two substances frequently form parts of the same deposit and yet are distinctly separate from each other. In such cases the question arises as to why the iron and manganese are not intimately mixed in the form of a manganiferous iron ore, as would be expected if they had been precipitated together. Moreover, deposits sometimes occur which are composed largely of manganese ore, with little or almost no iron, and when the source of the manganese is looked for, we often find that the rocks which probably supplied it contained both manganese and iron, and that the iron was present in a much larger proportion as regards the manganese than in the new deposit. Here again the question arises as to why the iron and manganese are not in the same relative proportions in the new deposit as they were in the rocks from which they were derived.

Four principal causes suggest themselves in explanation of this separation:

(1) It might be supposed that the deposits containing mostly iron and those containing mostly manganese received these constituents from waters derived from different sources, and carrying iron and manganese only in the proportions in which they deposited them. Under some conditions this explanation might suffice, but in many cases, such as when iron and manganese alternate

along the same geologic horizon, and yet in close proximity with each other, the explanation is entirely inadequate, for the deposits are too close to each other to have been formed from different supplies of surface waters.

(2) It might be supposed that the iron or the manganese had been leached out of a deposit of the mixed ores, leaving one free from the other and depositing the dissolved ore somewhere else. This explanation, except in special cases, also appears inadequate, because the reagents in surface waters, which dissolve iron and manganese, seem to affect both about equally, so that if one were dissolved, the other should be taken up in the same way. Doubtless small differences could be found in the behavior of the organic and inorganic compounds in surface waters towards iron and manganese minerals, but they would be small as compared with the more active reactions which go on.

(3) It might be supposed that a separation could be produced by secondary concentration such as segregation, replacement, etc. This has doubtless sometimes been the case, but where the concentrating action is not assisted by a difference in the chemical behavior of the two substances, the separation would only be on a small scale. Even in the case of concentration by replacement of limestone, if iron and manganese both acted in the same way during the replacement, it would be expected to find them deposited in an intimate mixture. Though this secondary concentration, therefore, unassisted by other agencies, would not produce all the results found in nature, yet, when it is thus assisted, it often plays an important part.

(4) The fourth, and what seems the most important, factor in the separation of iron and manganese, is that, though very often they are precipitated in the same form from the same solution, yet sometimes they are precipitated in different forms; and even when precipitated in the same form, the precipitation of one sometimes requires different conditions from the precipitation of the other. This fact will explain the alternate association and separation of iron and manganese, not only when no secondary concentration has gone on, but also in cases where

such concentration has taken place, such as in the replacement of limestone, etc.

It will now be attempted to show how the various degrees of association and separation of iron and manganese found in nature may be produced by different conditions during deposition.

THE FORMS OF IRON AND MANGANESE DEPOSITED AT ORDINARY TEMPERATURES.

The mineralogical forms in which iron and manganese are deposited from solution in nature at ordinary temperatures depend on the conditions of air and water, whether of an oxidizing or a reducing nature, and on the character of the associated organic and inorganic matter either in solution or on the floor of the sea, lagoon or bog in which the deposition occurs.[1] There are four principal methods by which iron and manganese are precipitated in nature from surface waters:

(1) By oxidation, as in the case of the precipitation of hydrous oxides and in the precipitation of the carbonate by the partial oxidation of more complex organic salts.[2]

(2) By reduction, as in the precipitation of sulphide of iron by the reduction of sulphate of iron.

(3) By gaseous or soluble precipitants, as in the precipitation of sulphide of iron by the action of sulphuretted hydrogen or a soluble sulphide on a soluble salt of iron, and as in other cases to be mentioned later.

(4) By replacement of carbonate of lime or some other substance. Different forms are precipitated by these different methods.

Iron at ordinary temperatures is usually deposited from solu-

[1] The solutions may be precipitated, as already shown, either with or without admixture with mechanical sediments; and there are in nature all gradations from almost pure deposits of iron and manganese ore to beds of shale, sandstone, etc. stained with iron or manganese. Subsequent concentration frequently causes decided changes in the latter deposits (see p. 370).

[2] It has been suggested by A. A. Julien (Proceed. Amer. Assoc. Adv. Sci., Vol. XXVIII., 1879, p. 356) that in some cases the carbonates of iron and manganese may be only the fixed residue of organic compounds of more complex form once in solution in surface waters.

tion as the hydrous sesquioxide, the carbonate, the sulphide or the hydrous silicate of iron and potash known as glauconite. Manganese under similar conditions is deposited as the hydrous oxide[1] or as the carbonate, and possibly sometimes, though very rarely, as sulphide.

When solutions of organic or inorganic salts of iron and manganese are freely exposed to the action of air, as in shallow or rapidly moving streams, or in lakes and some bogs, they are quickly oxidized and both may be deposited as more or less hydrous oxides. In many bogs, however, the metals may be precipitated as hydrous oxide on the surface where oxidizing agencies predominate, but when these oxides sink and come into contact with decaying organic matter, free from the active oxidizing influences of the air, they may be reduced to carbonates.

The carbonates of iron and manganese may be precipitated when the solutions containing them are protected from oxidation by a reducing agent, such as decaying organic matter, or by being far removed from the air. Carbonate of manganese, however, is a much more stable compound than carbonate of iron, and the oxidizing conditions are often sufficiently strong to cause the deposition of iron as hydrous sesquioxide and not strong enough to change the manganese from its carbonate form. It is not uncommon, therefore, to have iron deposited in one place as hydrous sesquioxide, and manganese carried further on and deposited as carbonate, or even under special conditions deposited as carbonate with the hydrous sesquioxide of iron. Fresenius[2] has shown that the warm springs of Wiesbaden, which contain iron and manganese among their other mineral constituents, deposit iron in the form of hydrous sesquioxide, while manganese is carried on further in solution and deposited as carbonate. In this behavior, therefore, we have the first striking difference in the deposition of iron and manganese, and it will be further discussed later on.

[1] This oxide is generally in the form of the peroxide or the sesquioxide in a more or less hydrous condition.

[2] Jahrb. des Vereins f. Naturkunde in Herz. Nassau, Vol. VI., p. 160 (Bischof).

The sulphides of iron and manganese differ very much in their nature and mode of occurrence. Iron is frequently deposited as sulphide, but manganese rarely occurs in that form, and when it does it is always in very small quantities. Iron forms several sulphides in nature: pyrite (FeS_2), marcasite (FeS_2),[1] pyrrhotite ($Fe_{11}S_{12}$), troilite (FeS) and numerous other more complex compounds unnecessary to enumerate here. Pyrite is the commonest form of iron sulphide, and occurs in rocks of all ages, from Archean to Recent. It is formed in nature by the action of soluble sulphides or sulphuretted hydrogen on soluble salts of iron, and also by the reduction of sulphate of iron by organic matter or other reducing agents. Manganese forms two[2] sulphides, alabandite (MnS) and hauerite (MnS_2). Both minerals are very rare, and so unstable that they rapidly oxidize on exposure. Alabandite is the less rare form, and usually occurs as a subordinate constituent of certain metalliferous veins or allied deposits.

Though the sulphides of manganese are easily oxidized, they are not so unstable that, had they ever been formed in considerable quantities in sedimentary deposits, they would, even at considerable depths, have left no trace of their former presence. Moreover, the sulphide of manganese, as produced artificially,[3] is soluble in certain organic acids, notably acetic, and, as the conditions for the deposition of sulphides of metals in sedimentary deposits generally require the presence of organic matter, it is not improbable that some of the acids given off by such matter would be capable of dissolving sulphide of manganese. Here, then, is one reason why manganese might not be deposited as sulphide under some conditions which would cause the precipitation of sulphide of iron. Moreover, the artificial formation of sulphide of manganese (alabandite) in the laboratory is brought

[1] Marcasite has the same composition as pyrite, but differs in crystalline form.

[2] Manganese also occurs in the mineral youngite, which contains lead, zinc, iron, manganese and sulphur, but the mineral is considered of doubtful homogeneity. (See System of Mineralogy, E. S. Dana, 1892).

[3] When manganese is precipitated artificially as sulphide it is usually in the form of the monosulphide (MnS), in either a hydrous or an anhydrous form.

about most easily at high temperatures. It has also been noted that when manganese, in the form of the alloys spiegeleisen and ferro-manganese, is added to molten steel, it bodily removes a part of the sulphur; and it is thought by some metallurgists, that sulphide of manganese is formed and carried into the slag.

These and other indications of the more easy transition of manganese into the form of sulphide at high rather than at low temperatures afford another cause which might prevent sulphide of manganese from being formed in sedimentary deposits, for such deposits are usually laid down at ordinary temperatures. On the other hand, they also afford a cause which might lead to the deposition of the sulphide of manganese in certain metalliferous veins and other deposits, where the temperature at the time of deposition may have been high.

In many of the silver and lead deposits of the Rocky Mountains manganese oxides occur with the superficial oxidation products of the sulphides of other metals, and it has often been suggested that the manganese also was originally in the form of sulphide. This may be true in some cases, for alabandite has been found in a few metalliferous deposits in Colorado, Mexico, Germany, Peru and elsewhere, but in most cases, at least in the Rocky Mountains, when the level is reached at which the oxidized forms of lead, zinc, iron and other metals pass into sulphides, the manganese passes into carbonate or silicate, and remains in one or both of those forms to all depths that have been reached.

In the deposition of iron and manganese as sulphide, therefore, there is a most marked difference of behavior, and here again is a good cause for the separation of the two substances in sedimentary rocks, as will be more fully explained below.

Iron is often deposited in sedimentary formations as the hydrous silicate of iron and potash known as glauconite, and composes the mass of the large greensand beds common in Cretaceous and Tertiary strata; but manganese is not found in an exactly similar condition.[1] Here again, therefore, is an import-

[1] Manganese occurs in various hydro-silicates, but they do not appear to be deposited as sedimentary strata in the same manner as glauconite.

ant difference in the modes of deposition of iron and manganese, which also will be mentioned again.

It will thus be seen that while some of the forms in which iron and manganese are deposited are the same, others differ very widely, and even similar forms are often deposited under different conditions. It is doubtless to these various forms and conditions of deposition that the alternate association and separation of iron and manganese in nature are due.

CAUSES OF THE ASSOCIATION OF IRON AND MANGANESE.

The very frequent intimate association of iron and manganese in sedimentary rocks is what would be expected from a deposition as oxide or carbonate in basins such as coastal lagoons or bogs, where the waters moved very slowly, or not at all, for under such conditions, they are often deposited together.[1] Moreover, it is a well-known fact that isomorphous substances have a strong tendency to combine in a homogeneous mass, and to crystallize together in different proportions. Carbonate of iron and of manganese are isomorphous with each other, and this is hence a possible cause of the frequent intimacy of their association, such as is seen in almost all manganiferous spathic iron ores, whether these ores are formed by direct precipitation or by replacement of carbonate of lime. The oxidation of such a mixture would give the common form of an intimately combined iron and manganese ore.

Since there is usually more iron than manganese in the rocks from which both metals were originally derived, the surface waters draining from areas of such rocks usually contain the metals in a similar proportion. Hence, in cases where the deposition of the carbonates of both occurs at the same spot, the isomorphous carbonates derived from the solutions have a larger percentage of carbonate of iron than of carbonate of manganese, and the resulting oxides contain the two metals in the same

[1] If the water moved very slowly, the deposition would probably take place approximately in the same spot; if the waters moved more rapidly, the iron might be deposited in one place and the carbonate in another, in the way explained on page 363.

proportion, thus giving rise to the common low-manganese iron ores.

The hydrous oxides of iron and manganese, however, are not isomorphous,[1] and, therefore, when they are precipitated together, as in bog-deposits, the association is often much less intimate than in the cases just mentioned, and is simply due to the fact that, under certain conditions, the oxides of both metals are precipitated in the same place.

CAUSES OF THE SEPARATION OF IRON AND MANGANESE.

When iron and manganese ores occur in more or less separate deposits, it becomes necessary to suppose the action of influences different from those which cause the deposition of both together, and such influences are to be found in the different modes of precipitation, under certain conditions, of the two metals. It has been shown by Fresenius[2] that certain warm springs, on reaching the surface, first deposit hydrous sesquioxide of iron, and farther on carbonate of manganese. This not only points to the well-known fact that carbonate of iron is more easily oxidized than carbonate of manganese, but it also leads to the belief that the bicarbonate or other salt of iron in the water is more easily oxidized than the manganese salt.

An action somewhat similar to that described by Fresenius readily explains the occurrence of manganese sometimes in entirely separate deposits, sometimes in distinct but closely alternating deposits.[3] Under certain conditions, if the waters from which the precipitation took place were moving, the iron and manganese, owing to the difference in oxidability, as stated above, would be laid down in different places, resulting in the formation of deposits of iron ore free from manganese, and manganese ore free from iron in different positions along the plane of the same geologic horizon. Such occurrences are often seen in the iron

[1] The hydrous oxides of iron are not crystalline. [2] See p. 363.

[3] Bischof suggests that the action described by Fresenius causes the separate deposition of iron and manganese; and also that it explains the occurrence of large deposits of manganese ore in regions where the iron ore contains least of that ingredient. (See Elements of Chemistry and Phys. Geol., Vol. III., pp. 531–532.)

regions of the Appalachian Valley, where there are often found, in different places along the same belt, deposits of iron ore and deposits of manganese ore in positions similar with relation to the enclosing rocks.

These conditions of moving water might also cause the occurrence of the two ores in interstratified layers, as is sometimes the case. Such a condition would result if iron were deposited in a certain place at one time, and if, later, on account of some increased facility for oxidation, iron was deposited before it reached that place, and the manganese, being less easily precipitated, were carried on and laid down upon the first deposit of iron.

Suppose the metalliferous solutions to be confined in a shallow basin, or, at least, to pass through it so slowly that they become thoroughly oxidized. Under such conditions the deposition of iron and manganese would go on continuously, and so nearly on the same spot that a comparatively homogeneous manganiferous iron ore would be formed. If the supply of metalliferous solutions were not continuous, but were intermittent, as is sometimes the case in local basins, such as coastal lagoons, which are often dependent for their supply of water on the changes of season and the sudden fluctuations of weather, then interstratified layers of iron and manganese ore might be produced. The iron, becoming oxidized on the surface, sinks to the bottom, possibly in some cases to be converted there to the simple carbonate by organic matter. Further oxidation precipitates hydrous oxide or carbonate of manganese on top of the iron. A renewed supply of surface waters brings more solutions of iron and manganese, or else the evaporation of the water in the closed basin concentrates the materials which have not yet been precipitated. In either case there is a further alternate deposition of the two ores.[1]

Another process of separation of iron and manganese in nature might take place by the formation of sulphide of iron. It has already been shown that iron is sometimes deposited as sulphide and later oxidized in the same manner as the carbonate.

[1] In some cases these iron and manganese deposits are undoubtedly formed by the replacement of limestone or other rocks, as is further discussed on pages — to —.

Manganese, on the other hand, is rarely found as sulphide, and there is reason to think that the sulphide never represented the original form of any large sedimentary deposits of manganese ore (see pages 364 to 365). It seems probable, therefore, that from a solution of iron and manganese in surface waters the iron might, where the conditions are favorable, be precipitated as sulphide (FeS_2) and the manganese might be carried on in solution to be deposited somewhere else as oxide or carbonate. Subsequently the oxidation of the ores would give rise to oxide of iron from the sulphide and oxide of manganese from the carbonate; and the two ores, though occurring at the same horizon, would be separated by a greater or less distance.

After the deposition of the sulphide of iron, the conditions might change and permit the deposition, in the same place, of the carbonates of iron and manganese together. This is an easy case to imagine, and where such a deposit was exposed to surface influences, the resulting product would be oxide of iron from the underlying sulphide and a manganiferous iron oxide from the overlying isomorphous carbonates. Hence another possible cause of the frequent association of pure iron ores and manganiferous iron ores. It is possible also that after the solution of iron and manganese had been freed from the former by precipitation as sulphide, the manganese might be carried on and laid down as carbonate on a previous deposit of iron sulphide, and when such a combination was oxidized, the result would be oxide of iron and oxide of manganese in beds closely associated but yet distinct.

By supposing the iron sometimes to be deposited in sea water as glauconite, a manner in which manganese is not laid down (see page 365), a further means of separation of the two metals would result.

Thus by alternating the conditions of the deposition of iron and manganese in different forms, a great variety of methods of association and separation of the two metals can be produced.

The above discussion refers not only to the deposits of iron and manganese ores of notable size, but also to the iron and man-

ganese frequently found disseminated through shales, sandstones etc. In these rocks they usually form a small but often a very important part, for in many cases the iron and manganese is taken into solution from the rocks and redeposited by a process of replacement with carbonate of lime in neighboring beds of limestone, or more rarely by replacement with other rocks, thus giving rise to important ore deposits. The question of the association and separation of the iron and manganese in these replacement deposits depends on a number of conditions, the principal of which are, just as in the class of deposits that has been discussed, the conditions during deposition and the forms in which the iron and manganese are precipitated. The processes by which association and separation occur in replacement deposits differ somewhat in detail from the processes just discussed, but are based on the same principles.

Many of the iron and manganese deposits of the Appalachian region are supposed by many to be replacement deposits.. N. S. Shaler[1] in 1877 suggested that some of the iron deposits of Kentucky and Ohio were formed by the solution of iron from certain rocks, and its deposition in the form of carbonates by replacement with underlying limestone. Subsequently it was changed by oxidation to brown hematite. A notable case of replacement has also been shown by R. D. Irving and C. R. Van Hise[2] in the iron deposits of the Penokee series of Michigan and Wisconsin. Here the ore is supposed to be partly a replacement of chert in a trough between quartzite and igneous rocks. The solution that contained the iron was derived from strata in the same series of rocks in which the iron was re-deposited and contained a certain amount of manganese. It is shown how the iron and manganese were more or less separated in the replacement process and that the separation was due to the difference in the oxidability of the carbonates as explained on page 363.

R. A. F. PENROSE, JR.

[1] Kentucky Geol. Survey, Report of Progress, Vol. III., New Series, 1877, p. 164.

[2] U. S. Geol. Survey, Tenth Annual Report, 1888–1889, Vol. I., pp. 409–422.

SOME RIVERS OF CONNECTICUT.[1]

Outline.— Introduction.— Topography of Connecticut: The upland plateau, its origin, date, elevation, valleys sunk beneath its surface.— Lowland on the Triassic area. — Later oscillations.—Résumé of the topography.—Early drainage.—Re-adjusted streams.— Revived streams.— Unconformable rivers, consequent or superimposed.— Pleistocene changes; the Farmington, Quinnipiac, Scantic.— Abandoned gaps.

Introduction. In order to study intelligently the history of a river, one must first become acquainted with the present physical geography of the region in which the river lies, and know the stages of its development. Therefore, before classifying the rivers of Connecticut, I shall consider the topography of the state, and in a few paragraphs outline the successive cycles in the history of its growth. The scope of this article will not permit a discussion or even a full statement of the evidence on which these conclusions are based. They have been stated at considerable length by Professor W. M. Davis,[2] and the reader is referred to his papers for the complete discussion. His conclusions in respect to the physical geography are accepted here without question, and form the basis for the discussion on the rivers of the state.

Topography of Connecticut. Connecticut can be said to consist of two great areas quite distinct in topography and geologic structure.[3] On the east and on the west are the crystalline uplands which rise from sea level along the Sound to 1,700 and 1,800 feet in the northwestern part of the state, and to 600 and 700 feet in the northeastern. These uplands consist chiefly

[1] The author desires to express his obligation to Professor W. M. Davis for aid in the preparation of this article. It was first written under his direction and with the help of his suggestions when the author was in the graduate school of Harvard University. Prof. Davis is not responsible, however, for the statement of the views herein advanced, although in general it is believed that he is in accord with them.

[2] Amer. Jour. Sci. 3d ser., vol. xxxvii, 1889, p. 423. Bull. Geol. Soc. Amer., vol. ii, p. 545.

of gneiss and granite, probably of pre-Paleozoic age, which are now much folded, faulted and crumpled. Between these two areas of crystallines is a lowland belt of Triassic sandstone and shale, twenty to twenty-five miles wide, extending from New Haven north through the center of the state and including in its

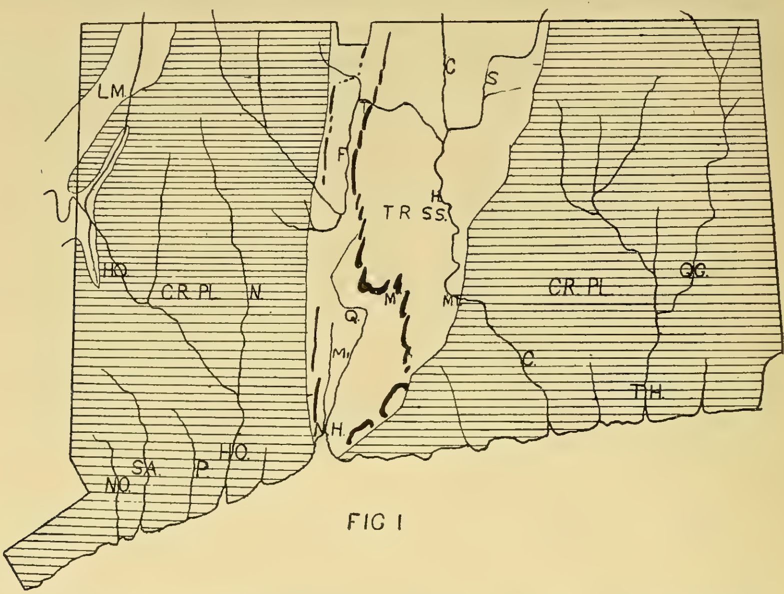


FIG 1

[3] The rough diagrams accompanying this paper may aid the reader who is unacquainted with the details of the region under discussion. The abbreviations on the above figure are as follows: C. The Connecticut. Cr. Pl. Crystalline plateau (the shaded area). F. The Farmington. H. Hartford. Ho. The Housatonic. Lm. Limestone area. M. Meriden. Mi. Mill River. Mt. Middletown. N. The Naugatuck. N. H. New Haven. No. The Norwalk. Q. The Quinnipiac. Qg. The Quinnebaug. S. The Scantic. Sa. The Saugatuck. T. Tariffville. Th. The Thames. The unshaded area is the Triassic sandstone lowland, and the blackened areas represent the ridges of the faulted trap sheets.

borders New Haven, Meriden, Hartford, New Britain and many towns of lesser note. These sandstones form a monocline with an eastward dip of 10° to 30°, and in addition to being tilted they have been faulted since their deposition in a shallow, slowly-subsiding trough of crystallines. Their thickness is variously estimated—3,000 to 5,000 feet, Dana; 10,000 or more, Davis.

This lowland is interrupted by a series of trap ridges, which in general present steep faces toward the west, whereas their eastward slope is gradual, less than the dip of the sandstones.

The upland plateau. Suppose we ascend the highest point of these trap ridges, the old tower on Talcott Mt., nine miles west of Hartford; we are 900 feet above the sea level and more than 600 above the plain at our feet. A few miles to the west across the sandstone valley, rise the crystalline uplands, which extend far to the north and to the south. On the east across the Connecticut we see the eastern uplands. The first impression, which comes to one as he gazes upon these uplands and which is strengthened with each view, is that few hills rise above the general level of the plateau; the crest line is nearly horizontal, declining gently to Long Island Sound. Above this general level are a few rounded domes, but no sharp, towering peaks. Below it valleys have been cut, but they do not destroy the plateau-like appearance. A view from the western plateau across the sandstone valley shows the remarkably even crest line of the trap ridges, a crest line which approximates in height the uplands on the east and west. A nearer view of the upland corroborates our first impressions of the gently rolling character of the inter-stream surfaces, but we have a better view of the valleys which have been sunk beneath the general level and of the low rounded hills which rise above it. In popular parlance the country is "hilly." It is uneven, not because there are high hills, but rather because there are deep valleys. If in imagination we fill up these valleys and the wide Triassic lowland to the general level of the broad inter-stream surfaces, we shall have constructed a gently undulating plateau, dipping to the south and east — a peneplain.[1]

Origin of the peneplain. This is not a constructional surface, for the rocks are greatly tilted, folded and faulted, so that the surface consequent upon such disturbance must have been complex and mountainous. Long subaërial denudation upon a folded and faulted mass when the land stood much lower than

[1] Am. Jour. of Sci., 3d ser., vol. xxxvii, p. 430.

at present produced this plateau. Evidently it could be produced by denudation only at or near baselevel, for the effect of erosion upon a mass high above baselevel is to accentuate its topographic relief, not to reduce it. We naturally ask ourselves, "At what stage in geologic history did this denudation occur?"

Date of the peneplain. The erosion which accomplished this great work must have commenced after the formation and dislocation of the Triassic beds, for the even crest line of the trap ridges, a part of which — perhaps all — were contemporaneous with the sandstones, is a part of the dissected peneplain; but to fix the date of the completion of the peneplain, we must turn to evidence presented in New Jersey.[1] There we learn that by the close of Cretaceous times, the country was eroded nearly to baselevel, and we may therefore speak of the relative position of the land and sea, to which the land was at this time reduced, as the Cretaceous baselevel, and this land surface as the Cretaceous peneplain.

Elevation of the peneplain. In post-Cretaceous, presumably early Tertiary[2] times, the land was elevated to nearly its present height and remained at that altitude, so far as topographic evidence shows, during Tertiary times. The proofs of this elevation are the valleys which the streams have sunk below the general level. That this was not a simple uplift, but was accompanied with tilting and warping, is clear from the following considerations. The depth to which a stream can cut its valley depends directly upon its height above baselevel. If the present surface were a peneplain uniformly elevated, the head waters and middle courses of a river would not be cut so deep in the surrounding plain as its lower course. But the reverse is true of the rivers of Connecticut. The depth of the valley increases inland, being greater in those regions where the peneplain was raised the highest. A comparison of the upper and lower valleys of the Housatonic, Naugatuck, Quinnebaug, and of the

[1] Bulletin of Geol. Soc. of Amer., vol. ii, p. 554.

[2] It is not desired to affirm that these periods of erosion and elevation began and ended promptly with the beginning or end of a period. The time statements must be considered as only approximate.

Connecticut at Middletown, where it enters the plateau, and at its mouth, will give some idea of the amount of the warping. It will not give an *exact measure* of it for several reasons: first, the upper courses of the rivers have not yet reached the present baselevel; second, the present altitude of the uplands is the result of the post-Cretaceous uplift and warping, plus a probable later post-Tertiary uplift (to be mentioned later), besides several minor oscillations, the last of which was downward, and is recorded near the coast in the drowned condition of the rivers. As has been already said, the peneplain is highest in the northwest, and gradually declines to sea level toward the south and east.

Consequences of the uplift. The consequences of this uplift are seen in the valleys, which are cut into the peneplain, and which have destroyed the level character of the country. In the hard crystalline rocks the valleys are generally narrow and deep, with bold slopes;[1] where they are cut in the crystalline limestone, they are wider and more open. In marked contrast, however, is the lowland on the Triassic area in which only the trap ridges remain to tell of the former altitude of the general surface, and the immense amount of erosion which has taken place on the soft sandstones and shales. Indeed erosion has progressed so rapidly on these soft rocks, that they have been worn down almost to a new baselevel in the same length of time in which the hard crystallines have been only trenched. This fact cannot be too strongly emphasized. The broad sandstone lowland from New Haven north into Massachusetts has been carved out of the uplifted peneplain in soft rocks, during the same time in which the Connecticut has excavated its gorge in the crystallines below Middletown, and the Housatonic has opened its upland valley on the limestones. The difference in results is due not to

[1] An exaggerated idea must not be had of the steepness and narrowness of these crystalline valleys. The valley of the Farmington, five miles up from where it opens into the Triassic sandstone, is 400 to 500 feet deep, and a mile and a half wide at the top. The Connecticut valley, just below Middletown, is about 400 feet deep and two miles wide at the top. These are fair representatives of the valleys in the crystalline rocks in the central part of the state.

a difference of time, but to the difference in the relative hardness of the rocks.

On the basis of this principle the age of certain river gorges to which reference will be made later can be fixed. The *narrow* passage of the Quinnipiac through a sandstone ridge southwest of Meriden cannot belong to the same cycle of erosion as the *broad sandstone lowland* on either side of it, but manifestly must be much younger. So, also, the narrow passage of the Farmington at Tariffville, where it crosses the trap ridge through a gorge free from drift, is of much later date than the *broader* valley more or less encumbered with drift which the upper part of the same river has cut in the hard crystalline schists. Cook's Gap in the trap sheet west of New Britain is much broader than either of the above, and belongs to the Tertiary cycle of erosion, although as I shall endeavor to show later, it was probably not occupied by a stream during the whole cycle. In marked contrast, also, with the Tariffville gorge is the gap by which the Westfield river in Massachusetts cuts the trap ridge. This gap was formerly broad and open — the result of Tertiary erosion — but is now filled with drift, in which the river is at present working. Since these two rivers are essentially the same in size, are now at the same level, and the rock is the same in both cases, the only explanation for the difference in the two passages is that they belong to different cycles.

To recapitulate, the results of the post-Cretaceous uplift are seen in the valleys which have been cut in the peneplain. The narrow valleys in the gneisses and schists, the upland valleys in the limestones, the wide open, drift encumbered gaps in the trap ridge, — Cook's and the Westfield river gaps, — the broad open lowland on the sandstones, are all the result of erosion in this cycle. The Quinnipiac gorge in the sandstone, and the Tariffville gorge in the trap are just as surely of a later date. They do not at all accord with the work of the earlier cycle either in size, angle of slope, or depth.

This conclusion is somewhat at variance with an opinion expressed by Professor J. D. Dana,[1] but it seems justifiable in

[1] Amer. Jour. of Sci., vol. x, 3d ser., 1875, p. 506.

view of the successive cycles in the physical development of the region. In another part of this article I shall consider these gaps again in connection with their river histories, and shall give additional reasons why I venture to differ from so eminent an authority.

Length of this cycle. This cycle of erosion beginning with the post-Cretaceous uplift was not so long as the preceding cycle. In the earlier one the whole state was reduced to a peneplain; in the later cycle only the soft Triassic sandstones were brought near to baselevel. It probably lasted through Tertiary times, and was brought to a close by a slight uplift. The result of this uplift is well shown in Pennsylvania[1] and New Jersey[2] It is not well shown in Connecticut, but there seem to be some traces of it in the trenches the rivers have cut below the level of the sandstone peneplain. However, these trenches are so much obscured by drift that a positive statement is not warranted. It may, however, be spoken of provisionally as the post-Tertiary uplift. There may have been later oscillations of small amount, probably were; here and there are shreds of evidence which point to such oscillations, but only one movement has had an effect upon the topography, which can be recognized. The fjorded condition of all the rivers along the Sound—the Norwalk, Saugatuck, New Haven bay, Niantic and Thames are the best examples—shows that within comparatively recent time there has been a slight subsidence of the land. But this movement is not to be compared in amount with those of the earlier cycles.

The drift. Over all the state in varying thickness lies the glacial drift, either in its typical unmodified development as till, or in its modified form, as river terraces, kames, eskers and sand-plains. It is of importance in this connection only as it has affected the topography of the country and so modified the drainage. Examples of these modifications will be mentioned later.

Résumé. There was first a long cycle of denudation in pre-

[1] McGee. Amer. Jour. Sci. 3d ser., vol. xxxv, p. 376.

[2] Davis and Wood, Geographic Development of Northern New Jersey, pp. 413, 414.

Triassic times, during which the contorted crystallines were worn down to a comparative level; second, a cycle of subsidence, deposition and volcanic outburst, during which the sea entered the crystalline trough, and the Triassic conglomerates, sandstones and shales were deposited with the intercalated layers of lava; third, a long cycle of elevation, folding, faulting and erosion, during which the sedimentary beds were elevated — tilted into the present faulted monocline, and this constructional surface worn down to a baselevel of erosion in late Cretaceous times. Each of these cycles probably represents the sum total of several subordinate cycles. There was, fourth, a post-Cretaceous uplift inaugurating a period of erosion lasting through Tertiary times and resulting in the formation of valleys in the hardest rocks, and a lowland approaching baselevel on the Triassic sandstones and shales; fifth, a probable late or post-Tertiary uplift, when the valleys were deepened and the lowlands trenched — obscure in Connecticut, but well shown farther south; sixth, the land, near the coast at least, is now slightly lower than it has been in the not remote past, as is shown by the fjords.

With the changes of the physical geography clearly in mind, the rivers of Connecticut may now be examined in respect to their conditions of origin, the number of cycles through which they have lived, and the approach they have made to mature old age. But at the very outset a serious difficulty is encountered, for the geological structure of the state is nowhere well described, nor have topographic maps of all the districts yet been issued. Since the structural details are to some extent unknown it is unwise in many cases to attempt more than tentative conclusions. Several of the problems to be presented cannot be considered as settled. Considerable progress toward a final settlement will have been made, however, if the conditions of the problems are made clear, various hypotheses suggested, and the attention of workers in this field called to these questions.

Early drainage. Of the drainage of Connecticut during Jurassic and Cretaceous times very little can be said. It is not even known whether it was consequent upon the Jurassic tilting

and faulting, or whether these deformations were so slow in their movement that the rivers persisted in spite of them. It may have been that the larger rivers were victorious, while the smaller were conquered and compelled to assume new consequent courses. Whatever was their origin there must have been abundant opportunities during the long erosion which resulted in the Cretaceous baselevel, and again in the period of revived and quickened degradation succeeding the post-Cretaceous uplift, for the streams to adjust themselves in a large degree to the geological structure. The contrast of hard and soft beds and the great elevation must have been potent factors in bringing to pass such a result. We expect to find the streams so far re-adjusted as to render improbable the discovery of their manner of origin.

The Housatonic, a re-adjusted stream. The best example of re-adjustment is found in the northwestern part of the state where the Housatonic and some of its branches follow well adjusted courses. From its headwaters, near Pittsfield, Mass., to New Milford, Conn., it has nearly all the way chosen its course along the Cambrian crystalline limestones in preference to the harder granites and gneisses on either side. The stratigraphical relationships of the limestone are not fully understood, but they seem to be deeply eroded anticlines and synclines, whose axes plunge north or south at various angles. The course of the river, if the drainage was consequent, was at first along the synclinal valleys, passing from one to another across the lowest points in the anticlinal ridge between them. But by a series of changes[1], resulting from the differential rates of erosion as hard or soft beds became exposed, the river previously to the Cretaceous baseleveling, seems to have re-adjusted its course to the softer limestones. However, there are several places where this conformity to structure does not seem to be the law; where the river departs from a limestone valley to flow for a time in the crystallines, only to return to the limestone again. The most marked instance of this is in the towns of Sharon and Cornwall,

[1] "Rivers and Valleys of Pennsylvania," Davis, W. M., published in The National Geographic Magazine, in 1889.

where the river leaves the limestone valley, which continues to the southwest, and flows for ten miles in a narrow gorge in the gneiss, only to again enter at its northern end a long narrow bed of limestone. The following seems to be the probable explanation. When the land stood at the elevation represented by the Cretaceous peneplain, these hard beds were below or but very slightly above baselevel, and were therefore undiscovered by the stream or had just begun to make themselves known late in the cycle. Had they been reached early in the cycle, when the stream was far above baselevel and presumably before many of its tributaries had been developed, and when it was therefore a smaller river, it is quite probable that further re-adjustments would have occurred, and the stream been led away from the hard rocks onto the softer beds to the west; but when they were reached the stream had cut so deeply and so nearly to baselevel that it was safe from capture. After the elevation of the peneplain the stream was revived and disclosed more and more of these hard beds, but was then, owing to the development and head-water growth of its tributaries, too important a river to be diverted by any rival. A river of this kind may be said to be "conformably superimposed" in distinction to one which is superimposed from an uncomformable cover.

Revived streams. It is important to recognize the effect of the post-Cretaceous uplift upon the rivers at that time established. As the land was baseleveled and the velocity of the streams decreased, they lost in large degree their cutting power and sluggishly meandered more or less in broad flood-plains. During and for a period after the uplift, their cutting power was restored to them by virtue of their increased velocity and they excavated the deep narrow valleys which we find in the crystalline highlands. The upper course of the Housatonic is a good example of a river re-adjusted to the structure during one cycle, revived by uplift to a second cycle of erosion, and in places "conformably superimposed" upon structures from which it would have been led away in the ordinary course of re-adjustment. Its tributaries, the East Aspetuck, Still, Shepaug, and Pomeraug

follow courses re-adjusted in one cycle and revived in a later uplift.

We can assert with the more confidence that such was the history of the upper Housatonic, because we find in other states, in regions whose history has been the same, similar examples of "conformably superimposed" and "revived" streams. The Musconetcong and Pequest, highland rivers of New Jersey, are streams "revived" from mature old age to vigorous youth and "conformably superimposed" upon saddles of gneiss between two limestone valleys.[1]

Unconformable rivers. In considering the course of the lower Housatonic we meet with some difficulty at the outset. In the southern part of the town of New Milford the river leaves the limestone belt which continues with some slight interruptions to the Hudson, and swings sharply into the crystalline plateau in a southeasterly course until it is joined by the Naugatuck, when their united waters flow south for a few miles to the sound. The course of the lower Connecticut is even more surprising. At Middletown it leaves the broad open Triassic sandstone lowland, and through a gorge enters the plateau, which has an average elevation of 600 to 700 feet. In this plateau of crystallines the river has sunk its valley nearly to sea-level. The slopes are steep compared to the lines in the sandstone lowland, and the contrast between the two parts of the river is one of the striking features of Connecticut scenery. Several theories may be framed to account for the curious behavior of these two rivers, but none of them are free from all difficulty.

As a consequent river. The lower Connecticut has been thought[2] to be a revived river, whose course was consequent upon the post-Triassic tilting and faulting. The faulted monocline seems to have had the shape of a half-boat, ends to the north and south, and one gunwale rising toward the west, the combined effect of the tilting and faulting being to swing the river to the southeast, where the keel of the boat was lowest. The proba-

[1] Davis, W. M., "Geographic Development of Northern New Jersey," p. 397-8.

[2] Davis, W. M., Amer. Jour. of Sci., 3d Ser. vol. xxxvii., 1889, p. 432.

ble existence of faults, with upthrow on the east, along the eastern margin of the Triassic rocks, is a difficulty in the way of the complete acceptance of this theory. Unfortunately too little is known about the structure of the western plateau to say whether the course of the lower Housatonic could be accounted for on such an hypothesis. On this theory the Connecticut would be consequent upon the Jurassic deformation, and revived by the post-Cretaceous uplift.

It may be suggested that the southeast courses are due to the tilting of the peneplain at the time of elevation, the plateau now being, as we have seen, much higher in the northwestern part of the state than elsewhere. But the acceptance of this theory necessitates a degree of smoothness and absence of even mild relief in the peneplain, which is hardly possible. The present average slope of the plateau is but a few feet per mile, and it seems incredible that so gentle a tilting could force rivers as large as these to take new courses. Besides, if the Housatonic and Connecticut were deflected, why were not the smaller streams—the Naugatuck and Quinebaug—also given southeastern deflections? Clearly, this explanation is not the correct one.

Superimposition. It has been suggested that these courses may be inherited from a Cretaceous cover, which formerly stretched over Connecticut for a considerable distance, but of which no traces now remain in the state. On parts of Long Island the Cretaceous deposits are found, and it is not inherently impossible nor improbable that they once stretched far over the main land. In New Jersey[1] several lines of evidence seem to show that the Cretaceous beds formerly extended across the Triassic, probably to the margin of the highland plateau. The curious drainage of the Watchung Crescent is one evidence of this, but the other proofs are along entirely different lines, so that there is apparently good evidence that the Cretaceous beds

[1] Geog. Devel. of Northern New Jersey, p. 404 et seq. Proc. Bos. Soc. Nat. Hist., Also Rivers of Northern New Jersey, p. 11 et seq. National Geographic Magazine, vol. ii, p. 93.

extended twenty-five miles or more farther inland. If, in the time which has elapsed since the deposition of these beds, there has been erosion sufficient to strip them off from such a broad area in New Jersey, may they not, in Connecticut, under presumably similar conditions, have been equally eroded ?

There is much which makes this hypothesis attractive, and, as the facts were first studied, it seemed the most likely one. It affords a good explanation, not only for the courses of the Housatonic and Connecticut, but also for other rivers along the sound. It seems, also, at first thought, to be well supported by analogy from New Jersey. But a closer study of the situation in that state reveals marked differences in the attendant circumstances. There the soft Triassic sandstone must have been worn down to a lowland early in the Cretaceous cycle, perhaps by the close of Jurassic time or thereabouts, while the harder crystallines retained a strong relief. The slight subsidence, which marked the beginning of marine Cretaceous in New Jersey, allowed the Cretaceous sea to transgress rapidly the baseleveled sandstones to the foot of the crystalline hills, but not to cover them to any extent. It is not probable that the crystallines in Connecticut had been brought nearer to baselevel than those in New Jersey at the time of the Cretaceous deposits. There is no evidence to show that the subsidence was greater in Connecticut than in New Jersey, and, therefore, from *a priori* considerations, the conclusion would seem to follow that the subsidence, which permitted the Cretaceous sea to cover the Triassic sandstone area of New Jersey, was not sufficient to permit the sea to cover the then unsubdued crystalline hills of Connecticut. Although this hypothesis is not to be hastily thrown aside, for theoretical reasons, yet it would seem necessary to hold it very lightly, at least until some positive proof is found of the former existence of the Cretaceous or some later formation in that region. The first suggestion, that the lower Connecticut was a consequent river in the Cretaceous cycle and was revived by the post-Cretaceous uplift, is, at the present state of knowledge, the most probable.

The Farmington. The roundabout course of this river pre-

sents another interesting problem, which is not free from difficulties. From its source in Massachusetts it flows southeast across the crystallines to the village from which it takes its name, where it turns abruptly north along the Triassic sandstones for ten or twelve miles, when with another wide sweep it crosses the trap ridges at Tariffville by a deep gorge. and resumes its southeasterly course to the Connecticut. Of this latter part I will speak later, but now arise the questions, "what has been the history of this river," and "why does it turn north at Farmington?"

The Farmington in the Tertiary cycle. A course more accordant with the structure would seem to be south along the Quinnipiac and Mill river valleys to the sound at New Haven. As has been said before (page 376), Prof. Dana has expressed the opinion that the gorge at Tariffville was occupied by the Farmington in Tertiary times, and that the Westfield river gap further north and the gorge of the Quinnipiac southwest of Meriden are also of earlier date than the glacial epoch. One reason has also been given why I differ from him in regard to the Quinnipiac and Tariffville gorges—they are narrower and steeper than those made in similar rocks during the Tertiary cycle. But more than this, the constructional topography, resulting from the tilting and faulting of the region, could not, it would seem, have caused the Farmington to take its present course. Even if it had taken this roundabout course during the baseleveling of the country, it must, since it would have had to cross three trap sheets, have been captured and led to the sea by the shorter and easier way along the sandstone area. The fact that the Connecticut probably persisted in its consequent course is no argument for similar conditions for the Farmington, because the latter is much the smaller stream, and so more easily captured. Nor could the river have been forced into this course during or after the post-Cretaceous uplift, for the land was then raised more at the north than at the south, and any changes from this cause would have been to confirm the river in its southward course. It is very probable, therefore, that in at least the latter

part of the Tertiary cycle, the Farmington did not have its present course, but followed the open sandstone valley, along the course of the Quinnipiac and Mill rivers of to-day. The earlier history of this river is purely conjectural; one fact may shed a little light upon it, a fact which may indicate that this course was an adjusted one taken during Tertiary times.

In pre-Tertiary times. Origin of Cook's Gap. A few miles southeast of where the river emerges from the crystallines, the trap ridge is cut by a deep wind notch—Cook's Gap—through which the New York and New England Railroad passes west from New Britain. As was pointed out some time ago by Prof. Davis,[1] this is not a fault gap, because the alignment of the ridge is not broken, but it is probably an abandoned water gap, the head-waters of the stream which formerly occupied it having been abstracted by a rival, which did not have to cross a hard trap ridge. Perhaps this river was the ancestor of the present Farmington, and in that case its history would seem to have been as follows. A stream consequent upon the constructional topography after the faulting and tilting at the close of the Triassic, it had its upper course on the crystallines, its lower on the sandstones and buried trap sheets. In its old age it crossed by a shallow gap the trap sheet, which had been uncovered by erosion. In the second or Tertiary cycle it was simply a revived stream quickened to a new life by the post-Cretaceous uplift of the peneplain. This uplift gave opportunity to a rival stream, which did not have to cross the hard trap beds to intercept the waters of the old Farmington, and lead them out by a shorter, easier path, probably down the sandstone valley west of the trap ridge. The path across the trap was abandoned, and the notch became a wind gap; the river following its new course, until the incursion of the ice-sheet interrupted its normal development. This is of course almost entirely speculative. Cook's Gap is best explained as an adandoned river gap; the Farmington is the nearest river of a size proportional to the size of the gap, and the

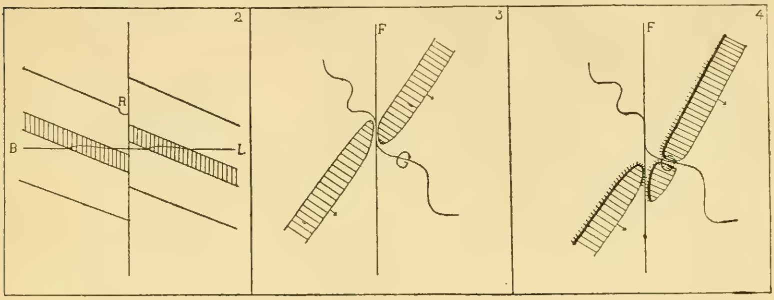
[1] Faults in the Triassic Formation near Meriden, Conn. Bulletin of the Mus. Comp. Zoöl. Harvard Univ. vol. xvi. No. 4, p. 82.

hypothesis is a rational one. There is, however, no direct evidence that the Farmington once occupied Cook's Gap.

The Tariffville cut. Before attempting to answer the second question, "why the river flows north at Farmington?" let us consider for a moment the history of the Tariffville cut. The river occupies a gorge whose sides are steep and talus covered, but which is not at all clogged with drift. There is naturally no room at or near the water level, even for the wagon road, place for which has been blasted near the top of the gorge. The profile of the gap shows a gentle ascent from the top of the gorge, up to the nearly level crest line of the ridge. That is to say, the recent gorge has been cut in the botton of a sag in the ridge. We have already given our reasons for believing that the gorge here is much younger than the Westfield river gap; that it is a part of the work of the next cycle; that it is post-Tertiary. The sag, however, in the bottom of which the gorge is cut, is clearly of the earlier cycle. The bottom of the sag is much above the level to which the rivers had cut their valleys in the late Tertiary, and, therefore, it is certain that a river could not have occupied it at the close of that cycle. It was probably an abandoned water-gap whose stream had been captured in the same way and in the same cycle as the river, which formerly occupied Cook's Gap.

The fact that the sag and gorge, although located very near a fault line, do not correspond to it, but are transverse and independent of it, is instructive and needs a moment's attention. It seems probable that the stream consequent upon the faulted blocks would have flowed down the slope of the tilted block and then along the fault line at the foot of the fault cliff and would have held this course during the baseleveling of the country. When the area was baseleveled the stream must have swung from side to side in its broad flood plain, and thus departed from the fault line. When it was revived by the post-Cretaceous uplift, it was confined to the course it had unwittingly taken on the sandstones just above the hard ridge, and it was forced to cut down through the trap. Subsequenlty a rival, which did not have

to work against this obstacle, abstracted its head waters and the gap was abandoned. The accompanying diagrams may make this easier to understand. Figure 2 is a cross-section of the faulted monocline, R showing the position of the river along the foot of the fault cliff. The line B L represents the surface of the country after baseleveling, the trap outcrops forming *low* hills (much exaggerated in the diagram). Figure 3 shows the dislocated trap sheets, the fault line and the winding course of the river, which has abandoned the fault line except where it passes between the low trap hills. Here the country is at base-level. Figure 4 represents the region after the elevation and resulting erosion. The trap ridges have become more pro-



FIGURES 2–4.

nounced, and have migrated eastward in the direction of the dip. The river has been slowly let down upon the northern one from the sandstone at point G and has there cut into the solid trap.

The transverse notch of Cook's Gap, already described, was probably located in a somewhat similar manner, but the case is not so clear as at Tariffville.

Gravel terraces of the Farmington. A consideration of some facts concerning the height and slope of the terraces along this part of the river may give a clue to the answer to our question. One-half a mile east of Tariffville and east of the trap ridge, the highest terrace is 210 to 215 feet. Half a mile south of the same place but west of the ridge the height is 275 feet.[1] The

[1] J. D. Dana, Amer. Jour. Sci. 3d. ser., vol. xv, p. 506.

top of the gorge at Tariffville is about 190 feet above the sea-level. It does not seem probable that these highest terraces were ever continuous over all the Farmington valley. But if they represent the level reached by the maximum flood accompanying the melting of the glacier, the great difference in their height on the two sides of the trap ridge, in connection with the other evidence already noted, gives strong reason for believing that the gorge as it exists to-day had not then been cut. A mile and a half east of Tariffville there is a lower terrace which is wide-spread. Its general height is about 190 feet, in places a little more. In this terrace the lower part of the Farmington has cut a trench 90 to 100 feet deep. The shape of the valley makes clear the fact that before this trench was cut the river flowed at about the 190 foot level, which is the height of the bottom of the sag at Tariffville. On the west side of the trap ridge there is also a more or less wide-spread terrace at about the same height. It seems very probable therefore that the river was raised to the level of the old sag in the trap ridge by the building of these terraces.

The present average southward slope of the highest terraces west of the trap ridge from Northampton, Mass., to Farmington, Conn., forty-four miles, is seven inches per mile,[1] and Professor Dana is inclined to believe that this is approximately the slope at the time the terraces were built. The character of the deposits shows that the current which formed these deposits flowed south. The present river, flowing north, falls twenty feet between Farmington and Tariffville, or 1⅔ feet per mile. The reversal of the river was probably determined by two factors. Near the village of Farmington, the waters of 200 square miles of territory are poured into the valley by the upper Farmington and its tributary, the Pequabuck. During the terrace building stage the great mass of débris contributed by these streams was deposited where the steep gradient of the highlands was exchanged for the gentle slope of the lowland. The main north and south valley was thus choked by the débris of its tributaries

[1] J. D. Dana, Amer. Jour. of Sci. 3d ser. vol. xxv, p 446.

and a long stretch of comparatively still water extended north from Farmington, in which nearly horizontal deposits were made. South of Farmington the terrace deposits are much coarser than to the north, and the face of the terraces is much greater. It is not impossible that, as the deposits between Farmington and the Massachusetts state line approached nearer and nearer to horizontality, the waters of the upper Farmington began to divide, part flowing north and part south, the northward flowing portion finding an outlet at the sag at Tariffville. If this was the case, the terraces between Farmington and Tariffville must have had a slight slope to the north. Their present southward slope could readily be accounted for by the re-elevation of the land after the disappearance of the ice. This explanation rests upon the ability of the upper Farmington and the Pequabuck to have completely dammed the southward flowing current and turned it northward by the great mass of their deposits. If this was not the case, and there may be some doubt on the matter, the subsidence which accompanied the later stages of the ice-retreat is the other factor in the problem. It is estimated that an average depression of 1.25 feet[1] through the Connecticut valley would restore it to an altitude approximating that at the close of glaciation. It seems highly probable that these terrace-deposits were built before the maximum depression was reached. If this was the case, the depression would be efficient in reversing the Farmington, and this factor would supplement the first. It is impossible at present to say to what extent these two factors enter into the problem. That they are not mutually exclusive is evident, and that they are together quantitatively competent seems certain. Among the several hypotheses which have been considered, this seems the most probable, and in the light of the present evidence the most rational.

At first thought it might seem that if the Farmington was reversed by the differential subsidence of the land, the Connecticut ought to have suffered a similar fate, and since it did not, the explanation cannot apply to the Farmington. But

[1] J. D. Dana, Amer. Jour. of Sci., 3d ser., vol. xxiii, p 198.

the terraces of the Connecticut have a much greater southward slope than those on the smaller river, and the depression was not sufficient to reverse the stream. The conditions on the two sides of the trap ridge were not the same.

To sum up, then, the history of the Farmington seems to have been as follows: Its original consequent course was southeast on the crystallines and perhaps across the trap ridge at Cook's Gap, from which course it was turned in the Tertiary cycle by a stream whose course was approximately that of the Mill river of to-day. The damming of the valley by the deposits of the Upper Farmington, and the depression in the north accompanying the ice retreat, reversed the river at Farmington, and it took a new course on the terrace deposits, escaping by the sag in the trap at Tariffville into the Connecticut valley.

The Quinnipiac. The gorge of the Quinnipiac, already mentioned several times, seems closely comparable to the gorge of the Farmington. It is not of the Tertiary cycle, and is best referred to the inter-glacial or post-glacial epochs. We should expect the Quinnipiac, instead of turning eastward, to cut through this sandstone ridge, to continue southward along the Mill river valley. Dana[1] finds from the heights of the terraces that the drainage of the terrace-building period was not along the Quinnipiac, but along the Mill river, and concludes that the Quinnipiac gorge was obstructed by an ice-dam. I have not as yet studied it enough in detail to do more than express the opinion here reiterated, that this gorge is later than the cycle in which the open sandstone lowland on either side of it was excavated. Its topographic form would put it in the cycle which has been called post-Tertiary.

The Scantic. In the Scantic we have a typical example of a river whose lower course is manifestly of a later date than the upper. In this it is similar to several of our Atlantic rivers, notably those of North Carolina, whose upper courses are on the Piedmont crystallines, being probably established previous to the Cretaceous baselevelling, and whose lower courses stretch

[1] J. D. Dana. Amer. Jour. Sci., 3d ser., vol. xxv, p. 441.

seaward over the unconsolidated Tertiary deposits of the coastal plain. As the plain of these recent deposits emerged from the sea, the rivers were forced to extend their courses eastward over the freshly raised surface to the retreating shore line. The Scantic river has a similar history. Its upper course in southern Massachusetts on the crystalline plateau is a remnant of the drainage established before Cretaceous baselevelling and revived by the subsequent uplift. How much that revived drainage has been modified by drift can only be determined by long field study, but the topography, as read from the topographical atlas would seem to indicate, that it has not been much. The valleys were undoubtedly clogged with drift, and the drainage area may be somewhat modified, but the drainage seems to be substantially along the same lines.

Just below the village of Hampden, the Scantic leaves the plateau and enters the Triassic lowland. From this point to its mouth at the Connecticut, opposite Windsor, a distance of twenty miles, it flows nearly all the way through the gravel, sand and clay deposits of the period of ice-retreat. The topography of the lower course of the river is entirely characteristic of a stream which has recently attacked a level, easily eroded district. The inter-stream surfaces are broad and flat; the descent to the stream bed which is sunk seventy or eighty feet below the general surface is exceedingly steep. These two lines, that of the inter-stream surface and that of the valley side, meet at a sharp angle. The side streams are as yet very short, and have cut narrow gorges down to the main river. Tributary to them are deep side ravines, whose bottoms ascend rapidly to the inter-stream surface, the whole making a dendritic system of drainage in its earlier stages. The Scantic, having reached base level in its lower course, has developed a narrow flood-plain.

Manifestly this part of the river valley is of much later date than the upper part. If, during the period of ice-retreat, the lower Connecticut valley was an estuary, the Scantic was a much shorter river than at present. Its mouth could not have been far from the point where now it leave the crystallines, but as the

land was elevated and estuarine conditions gave place to fluviatile, the Scantic lengthened "mouthward," consequent upon the minor inequalities of the newly made beds. The effect would be substantially the same if the terraces were built by great valley floods, as Dana supposes. In pre-glacial times this river, in common with several other rivers rising on the crystallines and flowing into the Connecticut, had courses of various lengths over the Triassic sandstones, but these old valleys are lost entirely, the later trenches in the terrace deposits being altogether independent of them.

Other examples. The lower Hockanum, Farmington, Park, and the entire length of many short streams are similar to the lower Scantic, and originated under similar conditions. Stony Brook, a little stream north of Windsor Locks, presents the same features, but with this variation: It is superimposed through a thin layer of drift upon the sandstone, into which it has cut a deep, picturesque gorge. The Hockanum and Farmington are also "locally superimposed" in a few places. The Connecticut, also, north of Middletown, although following its pre-glacial valley, has departed in numerous places from its former bed, and has cut down through the valley-filling onto ledges of rock beneath. The water-power at Enfield, Conn., and at Turner's Falls and Bellows Falls, Mass., is the result of this superimposed position.

Abandoned gaps. Many abandoned water-gaps must exist among the hills of the state. Cook's Gap, through which the New York and New England Railroad crosses the trap ridge, three miles west of New Britain, has already been discussed. It must not be confounded with the majority of the other gaps in the trap ridge, which are oblique, break the alignment of the ridge, and are due to faults.

The New York and New England Railroad in ascending to the eastern plateau passes through Bolton Notch, a few miles east of Manchester. This notch, also, is an abandoned river bed but, as it seems, abandoned at a later date and for another reason than that assigned for Cook's Gap. The drift is very heavy in

this region, and the most probable explanation is that the post-glacial streams do not altogether follow pre-glacial valleys. This gap, used by turnpike and railroad, testifies of another and older drainage system.

That in this brief article all the problems connected with the Connecticut rivers have been solved, or even noted, is not to be expected. It is hoped, however, that the work done may prove a help to further study of the same regions, and that the tentative conclusions advanced may be substantiated by further investigation.

HENRY B. KUMMEL.

Studies for Students.

GEOLOGICAL HISTORY OF THE LAURENTIAN BASIN.

The study of the Pleistocene history of the basin drained by the St. Lawrence has been fragmentary and is still far from being complete. There is a lack of agreement in the interpretation of observations already made, due in part to the comparatively limited portion of the field examined even by those who have given the subject most attention, and in part to lack of uniformity in the standards of comparison used. It is with the hope of assisting in reaching more harmonious results that attention is here invited to methods of study.

In the present treatment of the subject it may be advantageously subdivided, and the facts and hypotheses relating to each division separately considered. Of the divisions that may be suggested the following seem the most important:

1. Character of the sub-morainal or hard-rock topography in the Laurentian basin.
2. Origin of the basin.
3. Sedimentary deposits.
4. Shore markings left by former water-bodies.
5. Fossils in ancient sediments, shore ridges, terraces, etc.
6. Fauna of the present lakes.
7. Changes in elevations of the land.
8. Former outlets.
9. Probable effects of an ice sheet on drainage.
10. Probable effects of a subsidence which would make the basin an arm of the sea.

1. *Character of the hard-rock topography.* In order to learn the character of the Laurentian basin it is necessary to

examine the rock surface beneath the general covering of glacial débris and stratified sediments which partially fill it. To do this, those areas in which rock in place forms the surface require to be mapped and their elevations noted; the records of wells and other excavations which pass through the superficial deposits should also be obtained and the character of the underlying rock ascertained, as far as is practicable. When sufficient data of this nature shall have been recorded, a contour map of the basin can be drawn that will reveal the shape of the depression with which the student has to deal. The depth of the present lakes plus an estimated thickness of clay and morainal material covering their bottoms, will probably furnish the only means of sketching contours over the deeper portions of the basin. Even an approximately accurate map of this character cannot be constructed for a long time to come, but every advance towards it will serve to make the problems to be studied more and more definite.

Something of the form of the rock-basin is already known and several deep channels in its borders, now filled with drift, have been discovered. The courses of buried channels connecting the basins of some of the present lakes have also been approximately determined. It is not necessary at this time to refer specifically to the discoveries that have been made, but it may be stated that enough is known to assure us that the basin is a depression in solid rock, the bottom of which is below sea level.

2. *Origin of the basin.* The rocks in which the Laurentian basin is situated are, with the exception of the Lake Superior region, nearly horizontal and belong almost wholly to the Paleozoic. The basin is essentially a depression in undisturbed strata, and all who have considered its origin seem agreed that it has been formed by excavation. A vast mass of horizontal strata has been removed, leaving an irregular rim of undisturbed rocks on all sides. The form of the depression is now obscured by drift; the deeper portions contain stratified sediments which have been deposited within it and it has been warped somewhat by orographic movement.

The manner in which the excavation was formed has been explained principally in two ways. One hypothesis is that it owes its origin to a time of subaërial denudation preceding the Glacial epoch, during which a valley, or series of valleys, was worn out by stream erosion; and that the depression thus produced has been but slightly modified by ice action. The closing of the ancient valley has been referred to orographic movements and to the filling of its outlet by glacial débris. Another hypothesis is to the effect that the excavation is mainly due to ice erosion during the Glacial epoch, without special reference to previous topographic relief. A warping of the earth's crust so as to produce a true orographic basin does not seem to require consideration, for the same reason as already stated, that the rocks in which the basin lies have been but little disturbed from their original horizontal position. Future study of the region must determine which of the two hypotheses outlined above best suits the facts; or if each hyphothesis has something in its favor, what combination of the two may be accepted as the final explanation.

It is a suggestive fact in connection with the first of these hypotheses, that the youngest rocks in the region antedating the Pleistocene belong to the Carboniferous. This seems to show that the land has not been submerged since at least the close of the Paleozoic. If not a region of sedimentation during this vast interval, it must have been subjected to erosion. The erosion of an ancient land surface might result in the production of topographic forms of diverse character, depending on its altitude, on the length of time it was exposed to atmospheric agencies during various stages of elevation, and on climatic and other conditions. The study of topographic forms is now sufficiently advanced to enable one to predict somewhat definitely what features would appear under certain conditions. We also know the characteristics of topographic forms due to glacial erosion. It seems evident, therefore, that a knowledge of the hard-rock topography in the Laurentian basin, would enable one to draw definite conclusions in reference to the part that ice and water each had in shaping the forms now found there.

The conclusion that the region under consideration has been glaciated is well established; it remains, therefore, to determine what topographic forms, if any, due to pre-glacial stream erosion can be recognized. As an example of this kind of evidence desired, attention may be directed to the northward facing rock escarpments which follow the southern shores of lakes Erie and Ontario for a large part of their courses and at varying distances up to several miles. These escarpments are composed of the edges of nearly horizontal strata, mostly of Paleozoic limestone, and their bases are buried beneath glacial debris and stratified clays so deeply that in some instances, at least, they do not reveal half of their actual height. These escarpments not only have Pleistocene deposits banked against them, but their faces and summits are polished and grooved, showing how stubbornly they resisted the invasion of the ice which impinged against them from the north. South of lake Ontario especially, the trend of the escarpment referred to is directly athwart the course of the ancient glaciers. The entire history of these escarpments cannot be discussed here, as my desire is simply to call attention to the fact that they existed before the Glacial epoch, and are relics of a strongly accented pre-glacial topography. They are within the southern border of the Laurentian basin, and hence afford means of determining, in part, what was the form of that basin before it was modified by ice action. Other similar escarpments exist in the northern and western portions of the same great basin, and as this study progresses it is to be expected that still other features of the pre-glacial land will be revealed. It is perhaps too early to decide what were the special topographic forms which gave character and expression to the St. Lawrence basin before the ice invasion, but the Erie and Ontario escarpments and some other similar features now recognized, suggest that in Tertiary times it resembled the present condition of the upper portion of the Mississippi valley, where bold, rock escarpments border wide stream-worn depressions.

Deep drift-filled channels are known to cut across the Erie and Ontario escarpments. These seem to have been formed

by streams tributary to the main drainage line to the north. If this conclusion is well founded, a study of the hard-rock topography should reveal other similar channels and finally indicate a well matured drainage system. If even the broader and stronger features of the pre-glacial surface can be determined, then the modifications due to glacial abrasion will become conspicuous, and the amount that glaciers have broadened and deepened the basin be determinable.

A study of the lithological character of the drift south of the present lakes should show, at least in a rough way, what portion of it was derived from the waste of rocks within the Laurentian basin. This inquiry has already been undertaken by at least two geologists, and estimates of the quantity of material removed from the basins of lakes Michigan and Erie respectively, have been made. This method may be extended so as to embrace a larger area, or some special portion of the great depression best suited for the trial may be selected. If the material removed from the basin or re-distributed within it by glacial action can be shown to be approximately equivalent in volume to the amount of rock excavated in order to form the depression, it would evidently tend to support the hypothesis of glacial erosion. If, on the contrary, the amount of débris derived from the basin should fall far short of what would be requisite to refill it, no very definite conclusion would seem to be indicated unless account could also be taken of the fine material carried away by glacial streams.

As the case stands at present it appears that there is evidence of a pre-glacial valley or series of valleys as has been claimed by several geologists, and that all but the boldest features of the old topography have been obliterated or greatly modified by glacial erosion followed by glacial and other sedimentation. Additional observations should show somewhat definitely the amount of work assignable to particular portions of the history. How far the results of subaërial and of glacial erosion have been modified by other agencies, more especially by orographic movements, has also to be considered.

If the St. Lawrence basin shall be shown to be largely the

result of subaërial erosion it will follow, unless it is found that the deeper portions are the result of glacial action, that the land at the time the streams did their work, must have stood higher than at present, for the reason that the bottom of the depression is now below sea level. Some idea of the smallest amount of elevation necessitated by this hypothesis might be obtained by estimating the gradients of the ancient streams and the amount of elevation required to bring the bottom of the depression up to sea level.

A study of the hard-rock topography in the valleys of the Ottawa and St. Lawrence and of the present submerged Atlantic border of the continent would also be instructive in this connection. The strict correlation of the topographic history of the interior and of the continent's margin may be difficult, but as the two regions are directly connected, valuable results should follow their comparative study.

The hypothesis that the Laurentian basin is due largely to preglacial erosion, necessitates also that the ancient system of river valleys should have been closed in some way so as to form the basins of the present and of former lakes. The closing has been referred to several agencies. An unequal subsidence following the period of stream erosion has been postulated. During the Glacial epoch the entire region was ice-covered and only glacial streams of one kind or another could have existed. On the retreat of the ice, when portions of the basin were abandoned, the drainage is supposed to have been obstructed by the ice itself, as will be noticed below. When the glaciers melted, a vast sheet of débris was left which in many instances filled or obstructed previous drainage lines. Old channels, now deeply buried, have been reported to connect the basins of the various existing lakes, as has already been mentioned, but no similar channel which could have afforded an escape for the waters of the entire basin has been discovered. Here again an acquaintance with the hard-rock topography should give assistance and indicate either that such a channel existed or that orographic movements have taken place which have obstructed the former drain-

age system. The glacial hypothesis assumes that the basin was excavated mainly by glacial abrasion and does not require that the land should be either higher or lower than at present. The study in this direction merges with that of the general glaciation of the northeastern part of the continent, and cannot be treated at this time.

3. *Sediments.*—Regularly stratified deposits of clay and sand occur along many portions of the borders of the present Laurentian lakes. These were clearly formed in water bodies which formerly existed within the Laurentian basin, and which in certain directions, at least, were of wider extent than the present lakes. The areas occupied by these deposits have been partially mapped, but much remains to be done in this direction. Fresh sections, particularly of the stratified clays, are exposed from time to time by artificial excavations, in which much of their history may be learned. Not only should records be made of the facts noted at special excavations, but the extent and character of the stratified deposits in one area should be determined and compared with similar data obtained in other areas. For example: the clays covering large tracts on the west shore of Lake Michigan and on the southern and western border of Lake Superior are of a red color, while other areas bordering Lake Erie are covered with blue clay. These two deposits have been supposed to have been laid down at the same time and in the same lake. The definite correlation of the clays of these two areas by direct contact, however, does not seem to have been made, and there are reasons for thinking that they may be quite distinct and that they originated in separate lakes.

The outer limits of the deposits of clay and sand here referred to are known in some instances to be determined by ancient beaches and terraces. Such associations of deep and of shallow water deposits require special attention, as the study of one may assist in interpreting the significance of the other. The fine, evenly stratified clays frequently contain large angular bowlders, which appear to have been dropped from floating ice and to show an intimate connection between the

ancient lakes and neighboring glaciers. The possibility, however, of the bowlders having been brought into the ancient water bodies by rivers, or floated outwards from the shore by lake ice, should also be considered. Huge angular masses of limestone have been reported as occurring in southern Michigan especially, which rest on superficial deposits and are thought to have been carried northward by lake ice. The relations of these masses to well defined shore lines have never been determined. If it should be found that they are above all former shores, it is evident that they must have been carried by some other agency than the one mentioned.

A chemical examination of the clays, or of their contained water, may indicate whether or not the basin was formerly in direct communication with the ocean. Analyses of the clays of the Champlain valley and of the similar clays in the Ontario and Erie basins might indicate whether or not they were deposited under similar conditions.

4. *Shore records.* Beaches and terraces have been studied at many localities about the borders of the present lakes, sometimes at a distance of more than twenty miles from their margins and at various elevations up to several hundred feet above their surfaces. In some instances these ancient shore records have been followed continuously for scores of miles. The tracing and mapping of individual beaches is one of the most important parts of the study here outlined, and is already well advanced. Confusion has unfortunately arisen, however, for the reason that topographic features, due to shore action, have, in some instances, been confounded with somewhat similar features due to other causes. Moraines and gravel ridges, formed by glacial streams, have been mistaken for beach ridges, and terraces of various origin have not been clearly discriminated.

In order not to be led astray by topographic forms that simulate shore phenomena, the student should examine the shores of existing lakes and learn what records are there being made. In the study of topography, "the present is the key to the past," just as definitely as in any other branch of geology. The

topography of lake shores has already received attention from one skilled in reading geological history in the relief of the land[1] and the study of existing shores in the light of what has already been done in that direction should enable even the beginner to avoid falling into serious error in interpreting ancient records of the same nature.

To be able to discriminate clearly between shore features and somewhat similar glacial phenomena, it is necessary to become familiar also with the topography of glacial deposits. Fortunately in this study also a guide is at hand[2] which, in connection with field observations, should soon train the eye to discriminate the shapes assumed by moraines and the deposits of glacial streams from all other topographic forms.

In examining the records of former lakes it will soon be observed that, in many instances, where the highest of a series of ancient beaches is obscure and indefinite, the topographic expression above and below a certain horizon, and also the character of the surface material, whether of the nature of lacustral clays and sands or of glacial débris, residual clay, etc., above and below the same level, are significant, and enable one to map the outline of a former water body with considerable accuracy.

In tracing ancient beaches and terraces, their forms and internal structure need to be recorded, so that the fact of their being true shore records may be made plain to others. The elevations of various well-defined points throughout the extent of an ancient shore should be carefully measured, for, as will be noticed below, although originally horizontal, they have, in many instances, been elevated or depressed, owing to broad general movements of the earth's crust. The continuous tracing of individual shore lines for as great a distance as possible is highly desirable, especially in a wooded country, in order to be positive as to which ridge or terrace measurements of elevation relate, and and also for the purpose of observing the nature of the changes that

[1] The Topographic Features of Lake Shores, by G. K. Gilbert, in Fifth Ann. Rep. U. S. Geological Survey 1883–4.

[2] Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch, by T. C. Chamberlin, in Third Ann. Rep. U. S. Geological Survey, 1881–2.

occur when a shore line gives place to other records. For example: some of the ancient beach ridges about the west end of Lake Erie have been found to be continuations of moraines. In other instances shore ridges have been reported to end indefinitely and to be replaced at the same general horizon by glacial records of various character. The correct interpretation of phenomena of this nature is especially important.

Accurate measurements of the vertical intervals between well defined beaches at many localities would enable one to identify special horizons, providing orographic movements were not in progress during the time the series was forming. This method has recently been successfully applied on the north shore of Lake Superior, where the character of the country does not admit of the tracing of individual terraces for considerable distances.

The deltas of tributary streams should also be revealed in the topography of the basin of an ancient water body. Changes in the character of lacustral sediments near where rivers emptied are also to be looked for. Sand dunes are frequently an important accompaniment of existing shores, and their association, perhaps, in a modified form, with ancient beaches is to be expected.

5. *Fossils.* Thus far only a few fossils have been found in the stratified clays and sands or in the ancient beaches of the Laurentian basin. Such observations as have been made in this connection indicate an absence of the remains of marine life and the presence, in a few instances, of fresh-water shells in all of the basin west of the eastern border of the basin of Lake Ontario. To the eastward of Lake Ontario, however, in the St. Lawrence and Champlain valleys, marine fossils are common in deposits supposed to be contemporaneous with the stratified clays to the west.

A careful search in the clays and beaches left by the former water bodies might be rewarded by important discoveries. In this examination microscopical organisms should not be neglected. If after a detailed examination no fossils are dis-

covered, this negative evidence would have its value, as it would indicate that the physical conditions were not favorable to life, and an explanation for this fact might be found. It is scarcely necessary to mention that care should be taken not to mistake the shells occurring in modern swamp deposits associated with the ancient beaches for true lacustral fossils.

About the borders of the present lakes and sometimes even below the level of the lowest of the ancient beaches the remains of the mastodon, elephant, giant beaver, elk, bison, deer, etc., have been found. The recency of the existence of such of these animals as are extinct may thus be established, as well as the former distribution of those still living in other regions.

Evidence of the existence of man has been reported from one of the old lake ridges in New York, and it is important that this interesting discovery should be sustained by evidence from other localities. Stone implements especially should be looked for in undisturbed lacustral clays, and in the gravels of the ancient beaches.

The remains of forests have been stated to occur in the lacustral clays adjacent to the south shore of Lake Erie. It is desirable to know the extent of these deposits and how continuous they are; also the character of the plant remains they contain, and whether they have been disturbed from the position in which they grew. Some of the questions that may be asked in this connection are: Was the basin drained and forest covered before the vegetable remains were buried, or were the plants floated to their present position, or did they grow on moraines covering the stagnant border of the retreating glacier and become involved and buried in morainal material as the ice melted?

6. *Life in the present lakes.*—The fauna of the present lakes has a bearing on their past history, for the reason that in the deeper parts of lakes Superior and Michigan crustaceans and fishes have been found which are believed to be identical with marine forms. These may be considered as "living fossils," and are thought by some to indicate that the lakes in which they occur were formerly in direct communication with the ocean. If

the occurrence of living marine species in the present lakes is found to be widely at variance with the history of the basin as determined from physical evidence, an inquiry should be made in reference to the manner in which the species discovered might migrate.

7. *Changes in elevation.* One of the most difficult problems in connection with the history of an inland region is the determination of changes of level. By leveling along an ancient beach, post-lacustral changes in the relative elevations of various points may be readily ascertained. Pre-lacustral changes, however, by which ancient valleys have been obstructed, are much more difficult of direct observation, but might appear from the study of the hard-rock topography, as has already been suggested. This branch of the investigation, however, should more properly begin at the coast and be extended inland.

8. *Former outlets.* Several localities where the waters of the Laurentian basin have overflowed during former high-water stages have been pointed out, but some confusion has arisen in this connection, for the reason that the channels formed by streams issuing from the margin of the ice during the closing stages of the Glacial epoch have, in some instances, been mistaken for evidence of former lake outlets. The old outlets which seem to have been well determined are situated at different levels, and show that the entire basin could not have been occupied by a single great water-body, unless, as has been supposed by some, it was in direct communication with the sea. This hypothesis will be considered below. It has sometimes been assumed that all of the basin below the level of some ancient outlet was once flooded, so as to form a great lake in all of the basin now situated at a lower level; but, in making such generalizations, the possibility of places in the rim of the basin being at a lower level than the outlet discovered, thus necessitating a special explanation, such as the partial occupation of the basin by glacial ice, or changes in elevation of such a character as to raise the locality of former overflow or to depress other regions, have to be considered.

Former outlets should bear a definite relation to neighboring shore lines and to sedimentary deposits. The channels leading from former points of discharge merit examination, as here again changes of level may perhaps be detected in the gradients of stream terraces.

Most of the ancient outlets thus far recognized lead southward, but as previously mentioned, a former channel of discharge north of Lake Superior has recently been reported. If this observation is confirmed, it will have an important bearing on questions relating to changes of level and to the position of the ice front during the later stages in the retreat of the glaciers.

9. *Probable effects of a retreating ice sheet on drainage.* The generally accepted conclusion that glaciers advanced southward and occupied the Laurentian basin during the Glacial epoch and retreated northward toward the close of that epoch, is sustained by a vast body of evidence. As the ice sheet withdrew it left a superficial deposit frequently one or two hundred feet thick over nearly all of the region it abandoned, and pre-glacial drainage lines were obstructed and mostly obliterated. As long as the slope in front of the ice was southward, the drainage from it found ready means of escape, but when the slope was northward towards the ice front, the drainage was obstructed and lakes were formed.

We have good reasons for believing that the topography of the Laurentian region was essentially the same at the close of the Glacial epoch as it is now, but the broader question of continental elevation is less definite. The inequalities of the surface being essentially as we now find them, it would follow that the first lake formed when the ice retreated to the north of the divide running through central Ohio and central New York, would be small and dependent on minor features in the relief of the land, and would discharge southward. As the ice retreated, the lakes would expand and become united one with another and the larger lakes thus formed would still find outlet across the southern rim of the basin. As the glaciers continued to retreat lower and lower, passes would become free of ice and the lakes

would be drained at lower levels, old beaches would be abandoned, the lakes would contract, and finally separate lakes would be formed in the lowest depression in the basins of the more ancient water bodies. The shape of the retreating ice front would be determined by topographic conditions and would in turn determine the northern outline of the lakes along its margin. This in brief is one hypothesis that has been proposed to explain the varied history recorded by the shore records, sediments, etc., within the basin.

10. *Communication with the sea.* Another hypothesis which assumes to account for some of the facts observed, is that the continent was depressed at the close of the Glacial epoch sufficiently to allow the sea to have access to the Laurentian basin. This hypothesis is coupled with others which do not recognize a period of Pleistocene glaciation, but, as already suggested, this is a matter that is considered by the great body of American geologists as not being any longer open to profitable discussion.

In the study here outlined the question whether the water bodies which formerly occupied the Laurentain basin were lakes or arms of the sea, should not be difficult of direct and positive determination. If fossils can be found within the basin, they might yield definite testimony, but even if they are absent or if their evidence is inconclusive, topography can be appealed to with the expectation of receiving a conclusive decision.

If the Laurentian basin was occupied by an arm of the sea during various stages in the Pleistocene elevation, then the records of such a submergence should occur both within and without the depression, and direct connection between the two should be expected. If the waters within the basin were capable of making such well-defined shore records as are now found, we are justified in assuming that the true ocean beach on the outer slopes of the basin would be still more conspicuous. Again, the waters within the basin deposited a sheet of sediment, certainly not less than one hundred feet thick ; to be sure the conditions for rapid accumulation were there present, but if the ocean covered the adjacent land it should have left similar de-

posits. This is abundantly proven in the St. Lawrence and Champlain valleys, where clays containing marine fossils occur up to a certain horizon and record a Pleistocene invasion of these depressions by the sea. If the adjacent Ontario basin was occupied by the sea about the same time that the Champlain valley received its filling of c'ays containing marine fossils, there is every reason to believe that the deposits and their contained fossils in each basin would have been essentially the same.

One of the best known of the ancient shore lines about Lake Ontario has an average elevation of approximately 500 feet above the sea. If the sea had access to the basin at the time this breech was formed, then at corresponding horizon without the basin especially, to the south and southeast, where the full force of the Atlantic's waves would have been felt, there should be still more prominent beaches.

Many well-defined shore lines in the Laurentian basin are much higher than the one just referred to, and if these were also formed during various stages of submergence, as has been claimed, it is evident that ocean beaches and ocean sediments of Pleistocene age should be looked for over nearly the whole of the eastern part of the United States. The student may easily answer this question for himself, and thus perhaps make a contribution to the subject here treated.

In the investigation here outlined, the work of previous observers should not be ignored, and every plausable hypothesis that has been advanced to account for the facts observed should be carefully tested. In writing these pages I have not quoted the writing of others, for the reason that a discussion of evidence has not been the aim in view, and also because the writings examined are so numerous that justice could not be done them in the space at command. That the literature relating to the subject is voluminous is indicated by the fact that an annotated bibliography of the Pleistocene history of the Laurentian basin, now in preparation, already contains over 200 entries of individual papers.

Israel C. Russell.

EDITORIALS.

THE Summer meeting of the Geological Society of America will be held at Madison, Wis., on August 15 and 16. The session of the American Association for the Advancement of Science will begin at the same place on the 17th of August and extend to the 23d. The Congress of Geologists, under the auspices of the Columbian Exposition, will begin at Chicago, on August 24, and continue its sessions so long as its work may require. Preliminary to this series of meetings, Professors M. E. Wadsworth and C. R. Van Hise will meet such geologists as care to visit the Lake Superior region at the Commercial Hotel, Iron Mountain, Mich., on the forenoon of August 7, and will act as guides during the week following. A carefully prepared scheme for the trip is announced, embracing visits to the leading points of interest in the Menominee, Marquette and Gogebic iron districts, and in the copper-bearing region of Keweenaw Point. Those who desire to participate in the excursion, or who wish information regarding it, should address Professor Van Hise, at Madison.

In connection with the meetings of the Geological Society and the American Association at Madison, there will be excursions to the Devil's Lake region, to the Dells of the Wisconsin, and to the driftless area, under the guidance of geologists personally familiar with the features of most special interest. The article of Professor Van Hise in this number is a timely presentation of some points of peculiar significance in the first named region, and will prove very serviceable to those who choose the excursion to that region.

It is proposed to hold the sessions of the Congress at Chicago at the Art Institute during the forenoons, leaving the afternoons free for visiting the Exposition. Experience has shown that a half day devoted to looking at exhibits, where there is

such a plethora of objects of interest as in the Exposition, taxes the faculties of observation to the full extent of their pleasureable employment. Attendance upon the Congress and the study of the Exposition will, therefore, it is thought, constitute agreeable and profitable complements of each other. Excursions to points of geological interest in the vicinity of Chicago will be privately arranged, if desired.

These three meetings, with the attending excursions and the study of the Exposition, constitute a rare combination of opportunities which will doubtless be embraced very generally by the geologists of the country. T. C. C.

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THE supply of numbers one and two of this JOURNAL remaining in the hands of the publishers has become reduced below the limit they desire to preserve for binding and for special purposes, and they would esteem it a great favor on the part of those who may have received duplicates, as sample copies or by the accidents of mailing while the lists were imperfect, if they would return such duplicates to them. They will gladly return the postage if the address of the sender is placed on the wrapper.

REVIEWS.

CRYSTALLINE ROCKS FROM THE ANDES.

Untersuchungen an altkrystallinen Schiefergesteinen aus dem Gebiete der argentinischen Republik von B. KÜHN. Neues Jahrbuch für Min., etc., Beit. Bd. VII., 1891, p. 295,

Untersuchung argentinischer Pegmatite, etc., von P. SABERSKY, *ib.* p. 359.

Untersuchungen an argentinischen Graniten, etc., von J. ROMBERG, *ib.*, VIII., 1892, p. 275.

TRAVELERS and foreign residents in South America are rapidly furnishing information relative, not only to the volcanic, but also to the older crystalline rocks composing the great Andes chain. Since the early observations of Darwin, [1] the petrographical collections made by Stelzner during his three years' residence, as professor, at Cordova (1873 – 1876) have been described by himself [2] and Franke, [3] while the results of detailed studies of the more extensive collections gathered by Stelzner's successor, Professor L. Brackebusch, are now beginning to appear. Professor Brackebusch's residence in the Argentine Republic lasted from 1876 till 1883, and during this period he made numerous scientific expeditions. [4] The petrographical material thus obtained has been confided to specialists in Germany for study. Three papers dealing with the crystalline schists (gneisses), [5] pegmatites, [6] and granites, [7] have recently appeared. The rocks of the granite contact-zones

[1] Geological Observations in South America, 1846.

[2] Beiträge zur Geologie und Paleontologie der argentinischen Republik; I. Geologischer Theil, 1885.

[3] Studien über Cordillerengesteine. Apolda, 1875.

[4] Reisen in den Cordilleren der argentinischen Republik, Verh. der Gesellsch. für Erdkunde. Berlin, 1891.

[5] Untersuchungen an altkrystallinen Schiefergestenien aus dem Gebiete der argentinischen Republik, von B. Kühn. Neues Jahrbuch für Min., etc., Beit. Bd. VII., 1891, p. 295.

[6] Untersuchung argentinischer Pegmatite, etc., von P. Sabersky, *ib*,, p. 359.

[7] Untersuchungen an argentinischen Graniten, etc., von J. Romberg, *ib.*, VIII., pp.

had been placed in Professor Lessen's hands before his death, while communications on other special groups are doubtless to be expected.

These investigations naturally suffer from the forced absence of all field observations on the part of their authors, but the purely petrographical study of the material brings to light many points of interest, while it furnishes the only sort of detailed information regarding the rocks of these remote regions which we can for the present hope for. It is here desired only to direct attention to a few of the most striking results obtained from the Brackebusch material by the three authors last cited.

Dr. Kühn's paper on the crystalline schists treats principally of gneiss, and offers little that is new. It is mostly occupied with additional evidence of structural and chemical changes due to dynamic metamorphism in the sense of Lehmann. The most noteworthy of these are development and microstructure of fibrolite ; production of augen-gneiss from porphyritic granite ; development of microcline structure in orthoclase by pressure ; secondary origin of microcline, microperthite and micropegmatite ; alteration of garnet to biotite and hornblende.

Dr. Sabersky's paper on the coarse-grained granites or pegmatites is entirely mineralogical, and is devoted principally to elucidating the structure of microcline. The author concludes that the well-known gridiron structure is due, not to two twinning laws (the Albite and Pericline), as has been generally supposed, but to the Albite law alone, in accordance with which the individuals form both contact and penetration twins, like the albite crystals form Roc-tourné, described by G. Rose.

Dr. Romberg's paper on the Argentine granites is much more extensive than the two preceding. It is embellished by seventy-two microphotographs, many of which admirably illustrate the special points described. He comes to several results of great petrographical significance, the most important of which relate to the origin of quartz-feldspar intergrowths in granitic rocks. He clearly shows that beside the original granite quartz there is also much of a secondary nature present. This is not microscopically distinguishable from the original mineral, but its later genesis is demonstrated by many careful observations on its relation to other constituents. The abundant secondary quartz is regarded as the product of weathering — principally of the feldspar, into which it has a peculiar tendency to penetrate. The

extreme sensitiveness of quartz to pressure is emphasized (as it has been by Lehmann and the present writer) and illustrated by undulatory extinction, banding, granulation and even plastic bending around other minerals. Dynamic action is regarded as the efficient cause of the secondary impregnation of feldspar by quartz, and a union of this with weathering of the feldspar as the source of the abundant and complex pegmatitic intergrowths of quartz and feldspar.

These results are important, and they will now doubtless come to be generally recognized. It is, however, of interest to observe in this connection that all which is here announced as new in regard to secondary and "corrosion" quartz was described and figured in even greater detail by Prof. R. D. Irving ten years ago. This does not appear to be known to Dr. Romberg, for he does not allude to it, but anyone who will turn to pages 99 to 124 and plates XIII, XIV and XV of the monograph on the Lake Superior Copper Rocks (vol. 5, U. S. Geol. Survey, Washington, 1883) will find his conclusions stated in almost the same language and with a much wider range of fact and illustration. Dynamic action is not here adduced as a cause for the saturation of feldspar by secondary micropegmatitic quartz, since the Lake Superior rocks show no evidence of having been subjected to pressure, but that the quartz itself has been derived from the leaching of the feldspar substance and that the impregnation is mostly confined to the orthoclase is clearly stated.

Dr. Romberg also demonstrates, in a number of cases, the secondary origin of albite, especially as microperthite, and of microline. He gives details relating to each of the mineral constituents, and then the effects of pressure and of chemical action on the most important of them. Among many interesting observations but a few can be even mentioned here; such, for instance, as the original character of muscovite in many granites; the alteration of garnet into muscovite; the dependence of the well-known pleochroic halos in biotite and cordierite upon the substance of the zircon which they almost invariably surround, and secondary rutile needles which grow out from biotite into both quartz and feldspar. In one rock occurring in a granite a violet, strongly pleochroic mineral was found, which, in neither composition nor physical properties, agreed exactly with any known species. It seems to be intermediate between andalusite and dumortierite, but, as its individuality is not yet perfectly established, no new name is proposed for it.

G. H. Williams.

The Mineral Industry, its Statistics, Technology and Trade, in the United States and Other Countries, from the Earliest Times to the End of 1892. Vol. I. Edited by RICHARD P. ROTHWELL, editor of the *Engineering and Mining Journal.* 629 pp., 8vo.

This volume is a statistical supplement of the *Engineering and Mining Journal*, and is published by the Scientific Publishing Co., of New York, 1893. It takes the place of the former annual statistical number of the *Engineering and Mining Journal*, and it is the first volume of a series which is to be issued annually. The object of the present volume is to make known, as soon as possible after the expiration of the year 1892, the statistics and the various conditions of the mining industry in that year and in previous years. The future volumes will, each year, bring these statistics up to date, and thus the full particulars of the mining industry will be known within a few days of the expiration of every year. The volume is a compilation of articles written by different authors, and the names of these writers are guarantee that the different subjects have been treated by authorities in the departments with which they deal. The editor himself, it is but justice to him to state, has written some of the most important parts of the volume, notably the article on the statistics of gold and silver, and his well-known familiarity with the subjects he discusses renders the reader confident of their accuracy.

The present volume is not confined to the bare presentation of figures of production and consumption of various mineral products, but it treats each individual branch of the mining industry in its various departments; and in this way the volume really represents a series of treatises on the various mining products and the methods of treating them. The production of each material is given not only for the United States but also for foreign countries; the conditions of the American and foreign markets during 1892 and previous years are discussed, while the various uses of the different materials, the history of mining in different districts, the means of transportation. the metallurgical methods of treating different ores, the methods of sampling, and the possibilities of competition in various mining industries are also described. In addition to this, tables of assessments levied and dividends paid by various mining companies are given. The volume ends with a concise statement of the statistics and condition, as well as the extent, of the mining industries of foreign countries. Thus there is presented, in a volume of no excessive size, a complete and concise

epitome of the mining industries of the world ; and this work was completed almost immediately after the time to which it relates.

The various subjects are treated in the following order: A resumé and tables of statistics of the mineral products of the United States ; articles on Aluminum, Antimony, Asbestos, Asphaltum, Barytes, Bauxite, Borax, Bromine, Cement, Chemical Industry, Chromium, Coal and Coke, Copper, Corundum and Emery, Cryolite, Feldspar, Fluorspar, Gold and Silver, Iron and Steel, Lead, Manganese, Mica, Nickel and Cobalt, Onyx, Petroleum, Phosphate Rock, Platinum Group of Metals, Plumbago, Precious Stones, Pyrites, Quicksilver, Salt, Soda, Sulphur, Talc, Tin, Whetstones and Novaculite, Zinc ; Tables of Assessments Levied by Mining Companies from 1887–1893 ; Tables of Dividends Paid by American Mining Companies ; Baltimore Mining Stock Market, Boston Mining Stock Market, Denver Mining Stock Market, London Mining Stock Market, Lake Superior Mining Stock Market, New York Mining Stock Market, Paris Mining Stock Market, Pittsburg Mining Stock Market, Salt Lake City Mining Stock Market in 1892, San Francisco Mining Stock Market ; Foreign Countries — Austria-Hungary, Belgium, Canada, China, France, Germany, Italy, Japan, Russia, South American Countries, Spain and Cuba, Sweden, United Kingdom of Great Britain and Ireland.

The importance of the subject treated in this volume can be appreciated when it is known that the products of the mines of the United States alone in the census year of 1889 amounted to $587,230,662, and that this amount really only represents the interest on an immensely larger capital invested. The mining products of the United States are far more important in their aggregate value than those of any other country in the world, though, in many individual products, other countries supply more than the United States. This country is first, however, in the production of pig iron and steel. It is also first in the production of copper, gold, silver, petroleum, and a number of other products. Great Britain is still the leader in the production of coal, but the United States' production is rapidly growing and already equals 81.08 % of the British production, and supplies 28.75% of the world's consumption.

Every subject in this volume is fully discussed, and at the same time nothing is given which is not appropriate and even necessary. Thus a combination of completeness and conciseness is reached which is excellent. Among the most carefully and exhaustively treated subjects are

copper, gold and silver, the platinum group of metals and coal and iron, though many others might be mentioned, for every subject undertaken has been thoroughly treated. In the article on copper the statistics of production and consumption, as well as the condition of the various domestic and foreign markets, are fully discussed by the editor, and, in addition, separate articles are also given on "American Methods of Ore Sampling and Assaying," by Albert R. Ledoux, and on "Bessemerizing Copper Matte," by Charles Wade Stickney. The article on the statistics of gold and silver is by Mr. R. P. Rothwell, editor of the volume, and is an excellent piece of statistical work, giving, as it does, the statistics of production of gold and silver in the world for a number of years back. To this article are appended interesting papers on the "Chronology of the Gold and Silver Industry, 1492–1892," by Walker Renton Ingalls, on "Recent Improvements in Gold Chlorination," by John E. Rothwell, and on the "Cyanide Process," by Louis Janin, Jr.

The article on the Platinum Group of Metals, by Charles Bullman, gives complete information regarding the production, consumption, nature of the deposits, metallurgy and uses of platinum and its related metals, iridium, rhodium, osmium, palladium and ruthenium. The articles on Coal and Coke and on Iron and Steel, both by Mr. Wm. B. Phillips, give full statistics of production and consumption, as well as interesting historical data, and reports of the condition of various markets. Many of the other articles in this volume deserve mention, but lack of space forbids further detail. It may be said, however, that everything necessary is presented, and nothing unnecessary or unreliable is given; in other words, the volume contains no trash.

One of the most noticeable features of the volume is the uniform and systematic manner in which the results are presented. The uniform arrangement of statistics is a matter requiring the greatest labor and statistical ability. Compiling a single table of statistics is a simple matter, but arranging a vast mass of statistics, relating to many diverse subjects, on a uniform and intelligible basis, is entirely another matter, and requires the highest skill of the statistician. In the Mineral Industry this has been accomplished in a most successful manner; everything is clear and intelligible at the first glance, and everything is in its proper place. A great detriment to the systematic presentation of statistics has been, as pointed out by the editor, the necessity

of using our present system of weights and measures, with "our long and short tons, our barrels of 200, 280, 300 or 400 lbs, our pounds avoirdupois and our pounds Troy, our bushels of a dozen different weights, and our gallons of several incomprehensible kinds"; but the disadvantages of this system have been partly avoided in many cases by giving the statistics in metric measures as well as in our own.

The question of the cost of production has been given especial prominence in this volume, with a view to showing the reduction in the cost of the crude products. To use the words of the editor: "The itemization of cost is the first essential step in securing economy in producing any article, and the history of every country and of every industry has shown that prosperity, whether national, industrial, or individual, is, in a general way, inversely proportional to the cost of supplying the rest of the world with what one produces." These reductions are in no way dependent on the reduction of wages. On the contrary, many of the mining industries where the greatest reduction in cost of production has been accomplished, are carried on with high priced labor; and in many other cases, where the wages are not high, the condition of the wage-earners has been greatly improved. The reduction in cost of production has been entirely brought about by improvements in mining machinery, by a more thorough understanding of the nature of the deposits to be worked, and by more intelligent management and labor. The reduction in cost of production is nowhere better seen than in the materials most necessary to our welfare. For instance, coal can in some cases be carried by rail for 400 miles and delivered on board vessels for from $2 to $2.25 per ton, and yet the mine owners and railroads make dividends; some of the manufacturing establishments in Western Pennsylvania obtain coal at from 60 to 75 cents per ton at their works; hard gold-bearing quartz can be crushed, washed and 95 per cent. of the gold saved on the plates for $1.25 per ton; high grade Bessemer iron ore can be mined, handled, shipped and delivered a thousand miles from the point of production for less than $4.00 per ton. All these figures seem almost incredible until one investigates the various devices which the ingenuity and better education of those engaged in the industry have invented for reducing the expenses of production.

The former annual statistical numbers of the Engineering and Mining Journal were excellent in all they undertook, but the present

volume, the Mineral Industry, makes a great advance in giving the statistics for foreign countries in addition to those of the United States. By so doing it gives the American producers an opportunity to know the present, past and probable future conditions of competition in foreign countries.

The two most important features in any statistical work are accuracy and promptness. The necessity of accuracy is self-evident, and without promptness the statistics lose much of their serviceability to those most interested in them, for the statistics of an industry published a year or two years late are rarely of much value to those engaged in that industry. The business man wants his statistics immediately after the expiration of the time to which they relate, so that he may know the existing condition of the industry in which he is engaged; but if he does not get these statistics until many months or even several years afterwards, the condition of the industry may have changed entirely since the time to which the statistics refer. It is the promptness with which this volume is issued, combined with a high degree of accuracy, far greater than would be expected in statistics so hastily compiled, that gives it its especial value.

In conclusion, it may be said, that as a piece of statistical work, relating to an industry that is world-wide in its scope, combining accuracy with full detail and systematic arrangement, and issued so soon after the close of the time to which it relates, the Mineral Industry has never been equaled in this country or abroad. The former statistical numbers of the Engineering and Mining Journal, which referred mostly only to American mining, were considered remarkable pieces of statistical work, on account of the promptness of their publication; but in the Mineral Industry we have an epitome of the mining operations of every quarter of the globe, published almost immediately after the close of the time to which they refer, a feat which heretofore would have been declared impossible. This accomplishment is most creditable to the editor, Mr. Rothwell, to the systematic organization of the Scientific Publishing Co., and to the business manager, Mrs. Braeunlich, by whose business ability such an expensive undertaking is made commercially practicable. The volume will be found of the greatest value to the economic geologist, the miner, the engineer and the business man.

R. A. F. Penrose, Jr.

Analytical Abstracts of Current Literature.

A New Tæniopteroid Fern and its Allies. By DAVID WHITE. (Bulletin Geological Society of America, 4 pp., 119–122, pl. I.).

Mr. White has described, under the name of *Tæniopteris missouriensis*, a new and well characterized fern from the Lower Coal-measures in the vicinity of Clinton, Henry County, Missouri. Botanically, it is of particular interest in that it combines the so-called tæniopteroid and alethopteroid types of structure, while geologically it is of much value in supplying a readily identified stratigraphic mark in a part of the Carboniferous not especially rich in fossil plants. After thoroughly describing it and considering its specific and generic resemblances, the author discusses at length its suggested genetic relations and represents in a graphic manner a scheme of its probable ancestors and line of descent. F. H. K.

Rainfall Types of the United States. Annual Report by Vice-President GENERAL A. W. GREELY. (The National Geographic Magazine. Vol. V., April 29, 1893, pp. 45–58 pl. 20).

The paper confines itself to the characteristic distribution of precipitation throughout the year and gives the rainfall types of the country.

(a) The best defined type of rainfall within the United States is that which dominates the Pacific coast region as far east as western Utah. The characteristic features are a very heavy precipitation during midwinter, and an almost total absence of rain during the late summer. (b) The characteristics of the Mexican type, dominating Mexico, New Mexico and western Texas, are a very heavy precipitation after the summer solstice and a very dry period after the vernal equinox. August is the month of greatest rainfall, while February, March and April are almost free from precipitation. (c) The Missouri type covers the greatest area, dominating the watersheds of the Arkansas, Missouri and upper Mississippi rivers, and of lakes Ontario and Michigan. It is marked by a very light winter precipitation, followed in late spring and early summer by the major portion of the yearly rain, the period when it is most beneficial to the growing grain.

Abstracts in this number are prepared by F. H. Knowlton, Henry B. Kummel, J. A. Bownocker.

(d) The Tennessee type, prevailing in Kentucky, Tennessee, Arkansas, Mississippi and Alabama, has the highest rainfall the last of winter, while the minimum is in mid-autumn. (e) The Atlantic type, covering all the coast save New England, is one where the distribution throughout the year is nearly uniform, with a maximum precipitation after the summer solstice, and a minimum during mid-autumn. (f) The St. Lawrence type is characterized by scarcity during the spring months, heavy rainfall during the late summer and late autumn months, with a maximum during November.

The regions lying between these several type-regions have composite rainfall types, resulting from the influence of two or more simple types.

H. B. K.

The Geographic Development of the Eastern Part of the Mississippi Drainage System. By LEWIS G. WESTGATE, Middletown, Conn. (American Geologist, Vol. XI, April, 1893, 15 pp.)

The drainage of the Eastern Mississippi basin in post-carboniferous was in all probability consequent upon the tilting which accompanied the stronger folds of the Appalachian revolution in the east. The present drainage is found to accord in the main with this hypothetical post-carboniferous drainage, but several streams depart quite widely from it.

(a) The great drainage lines of the St. Lawrence basin are structural valleys developed along the strike of the softer Paleozoic strata, and at right angles to the original surface. The streams seem, therefore, to have adjusted themselves to the differences in hardness and structure of the beds discovered. (b) The Ohio and Cumberland rivers cut directly across the Tennessee and Cincinnati anticlines. The most probable explanation is that the rivers were superimposed upon the arched and eroded Silurian rocks from a thin cover of carboniferous beds — now entirely removed. (c) The Upper Mississippi does not follow the dip of the rocks to the southwest, but follows the strike to the southeast. This part of the river probably dates from the elevation of the plains on the west and the Appalachians on the east, which marked the close of the Cretaceous and which left a broad north and south valley. (d) The author finds good reason to believe that the Lower Mississippi, in post-carboniferous times, flowed west through Missouri and Arkansas. The present course was probably taken at the close of the Cretaceous in consequence of elevations on the west and east, and possible depression in the south.

The Cretaceous base-level recognized by Davis on the Atlantic slope can be traced more or less discontinuously, and remnants of it are believed to exist in Kentucky, Tennessee, Wisconsin, Minnesota and Arkansas. But in general the work of the Tertiary cycle has obliterated almost all evidence of it on all but the hard sandstones and conglomerates of the Paleozoic series.

Good examples of the lowlands excavated from the Cretaceous base-level during the Tertiary cycle, are the Valley of the East Tennessee and the central lowland of Kentucky and Tennessee. During the post-Tertiary sub-cycle the larger streams trenched to greater or less extent these lowlands. No attempt is made to carry the history of the development of the Mississippi drainage into the complicated chapter of the ice-invasion. H. B. K.

On a New Order of Gigantic Fossils. By ERWIN H. BARBOUR. (University Studies. Published by the University of Nebraska. Vol. I, No. 4, July, 1892, pp. 23, pl. 5).

A part of Sioux County, Nebraska, lying north of the Niobrara River, has yielded a new order of gigantic Miocene fossils unlike anything heretofore known. They are best described as fossil corkscrews, of great size, coiling in right-handed or left-handed curves about an actual axis or around an imaginary axis. The screws are often attached at the bottom to an immense transverse piece, rhizome, underground stem, or whatever it may be, which is sometimes three feet in diameter. In other cases the corkscrew ends abruptly downward, as it always does upwards. In still other cases the transverse piece is variously modified, and sometimes blends into the sandstone matrix, as if the underground stem, while growing at one end, was decaying at the other. The fossil corkscrew is invariably vertical, and the so-called rhizome invariably curves rapidly upwards, and extends outwards an indefinite distance.

That they could ever have been formed by burrowing animals, by geysers or springs, or by any mechanical means whatever, is entirely untenable. Their organic origin is unquestionable. Microscopic sections show smooth spindle-shaped rods, which are suggestive of sponge spicules. From the numbers seen in place it is evident that they flourished in thickly crowded forests of vast extent.

A finely preserved rodent's skeleton was found in one great stem. The probable explanation is not that the rodent burrowed there, but that its submerged skeleton became an anchorage for a living, growing Daimonelix, which eventually enveloped it.

The author proposes this provisional classification:

Order.	Family.	Genus.	Species.
	Daimonelicidæ.	Daimonelix.	circumaxilis
			bispiralis.
———	———	———	anaxilis
			robusta
			carinata.
		———	———
		———	———

The different species are described in full. H. B. K.

The Vertical Relief of the Globe. By HUGH ROBERT MILL, D.Sc., F.R.S.E. Scottish Geographical Magazine, April, 1890.

The purpose of Dr. Mill's paper is to show a simple yet adequate basis on which to build the superstructure of physical geography. It does not attempt a discussion of the distribution and varieties of vertical relief. The structure of the earth is stated most simply by describing it as an irregular stony ball, covered with an ocean and an envelope of air. If the lithosphere were perfectly smooth and at rest, with the hydrosphere uniformly spread over its surface, the former would have the form of the terrestrial spheroid, and the latter would surround it to a depth of 1.7 miles. The surface of this hypothetical spheroid Dr. Mill calls *mean sphere level.* Of course, in reality the surface of the lithosphere is not perfectly smooth. Parts of it are greatly depressed and parts much elevated, the latter forming the land of the earth. The writer proceeds to calculate the position of mean sphere level, and in the absence of accurate data he uses the careful estimates of Dr. John Murray, which are as follows: Average depths of oceans = 2.36 miles; average height of land = .426 miles; average thickness of hydrosphere surrounding smoothed lithosphere = 1.7 mile; area of land = 55,000,000 square miles; area of oceans = 141,700,000 square miles. Suppose a block of 55,000,000 of square miles area and 1.7 miles deep to be cut out of the smoothed lithosphere and set down on the surface alongside the depression. No change will take place in the surface of the hydrosphere. If the surface of the 141,700,000 square miles of lithosphere were reduced to uniformity, the whole depressed area would lie .66 mile beneath mean sphere level, and the depth of the ocean becomes 2.36 miles. To raise the land to its actual mean level above the hydrosphere surface, a sufficient quantity of matter must be removed from the depressed area and placed on the elevated block. Let x = the thickness of the belt removed and y equal the thickness of the belt when placed on the elevated block. Then $x + y$ is the height of the land above the actual hydrosphere level. From the data given the following equations are easily obtained:

$$x + y - .426 = 0$$
$$141.7\,x - 55\,y = 0$$
$$x = .12 \text{ and } y = .306 \text{ in miles.}$$

The average height of the land above mean sphere level is thus 1.7 + .306 = 2.006 miles, and the average depth of the depressed portion beneath mean sphere level is .66 + .12 = .78 mile.

Dr. Mill divides the earth into the three following divisions: (1) *Abysmal area*, occupying all the depressions beneath the mean surface of the lithosphere, occupying 50 per cent. of the earth's surface; (2) *Transitional area*, comprising all the regions above mean sphere level covered by the hydrosphere, occupying 22 per cent. of the surface; (3) *Continental area*, all the lithosphere that projects above the hydrosphere, or 28 per cent. of the earth's surface.

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(*Further acknowledgments of pamphlets already received will be made in the next number.*)